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RECORD OF THE PROGRESS

OF

MODERN ENGINEERING.

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1865.

COMPRISING

CIVIL, MECHANICAL, MARINE, HYDRAULIC, RAILWAY, BRIDGE, AND OTHER ENGINEERING WORKS.

WITH

ESSAYS AND REVIEWS.

63622

EDITED BY

WILLIAM HUMBER

ASSOCIATE OF INSTITUTE OF CIVIL ENGINEERS; MEMBER OF INSTITUTE OF MECHANICAL ENGINEERS.

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TO

SIR JOHN THWAITES,

WHO, AS

CHAIRMAN OF THE METROPOLITAN BOARD OF WORKS,

HAS SO LARGELY

CONTRIBUTED TO THE HEALTH AND COMFORT OF THE METROPOLIS,

IN BRINGING TO A SUCCESSFUL ISSUE

THE WORKS HEREIN ILLUSTRATED,

This Volume

IS RESPECTFULLY DEDICATED

BY

THE AUTHOR.

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BIOGRAPHICAL SKETCH

OF

JOHN ROBINSON M'CLEAN, F.A.S., F.G.S.

JOHN ROBINSON M'CLEAN, C.E., F.A.S., F.G.S., J.P. (Staffordshire), Lieut.-Col. Engineer and Railway Volunteer Corps, President of the Institution of Civil Engineers, of whom we give a photographic likeness, forming a frontispiece to this volume, was born in Belfast in 1813, and educated at the Royal Academical Institution of that town. In 1834 he went to Glasgow University, where he studied under Professors Thomson, Meikleham, and Sir W. Jackson Hooker, during two sessions, and obtained high honours in the classes of Mathematics and Natural Philosophy, at the same time prosecuting studies of a practical character in Mining Engineering and Surveying.

In 1837 he entered the office of Messrs. Walker & Burges, Civil Engineers, 23 Great George Street, Westminster, and remained with them until 1844.

Mr. Walker was one of the most celebrated Engineers of that day, and acted for all the great public departments, including the Admiralty, War Department, Trinity House, &c.

Mr. M'Clean assisted in preparing the Surveys and Contract Drawings of the Improvements of the Harbour of Belfast (which have since been carried out so successfully by Messrs. Walker & Burges and Mr. Smyth); and from that time to the end of 1843 was more or less connected with the works undertaken by Mr. Walker, especially the embankment in front of the Houses of Parliament, Westminster and Blackfriars Bridges Coffer Dams, Commercial Docks, Tame Valley and Bentley Canals—the last of the great canals constructed in this country.

In 1844 Mr. M'Clean commenced, at Great George Street, Westminster, the independent exercise of the profession of a Civil Engineer, in which he has ever since taken an active and distinguished part.

During his first year of practice he became the Engineer-in-Chief of the Furness Railways, and has from that time to the present been intimately connected with all the great public works in that district, including the Barrow Harbour, Barrow Docks (as large as those at Birkenhead), Graving Docks, Railways, and other works. So great has been the progress resulting from the opening up of that part of the country by railways, that upwards of 200,000 tons of hæmatite pig iron and steel are now annually manufactured at the Port of Barrow, and 500,000 tons of iron ore are

annually exported from the district; while the population of Barrow, in 1844 numbering 130 persons, is now 16,000.*

In 1849 the public press commenced an agitation upon the polluted state of the Thames, which was becoming full of sewage, whilst several of the Water Companies then obtained their supply from the river, near London. Engineers were urged by the *Times* to compete for the honour of providing a remedy for the evil, and the Metropolitan Commissioners of Sewers invited competition for plans for the drainage of London on both sides of the Thames. In accordance with the advertisement, as many as 116 plans were sent in, although there was at that time no complete survey of London, and the Metropolitan Commissioners of Sewers furnished no information respecting the levels of existing sewers and streets, and it was necessary for the competitors themselves to be at great personal expense in procuring the requisite information to enable them to prepare plans. Mr. M'Clean, who had already devoted much attention to the drainage and water supply of the Metropolis, and had for three years before been occupied in bringing before Parliament a scheme for supplying London with 100,000,000 gallons of water daily from Henley-on-Thames, flowing by gravitation to the level of the Paddington Canal, sent in plans on this occasion.

The Commissioners appointed to examine and consider the whole of the competitive designs were—Lieutenant-General Sir J. F. Burgoyne, Bart.; Captain James Vetch, R.E.; J. M. Rendel, Esq., F.R.S.; Capt. H. D. Harness, R.E.; and Robert Stephenson, Esq., M.P., F.R.S.; and in March 1850 they published their Report, from which, with reference to Mr. M'Clean's scheme, we extract the following passage:—

"The best-conceived and most practicable scheme submitted to the Commissioners is, in our opinion, that of Mr. J. R. M'Clean; and though we do not deem ourselves justified in recommending any one of these schemes for adoption as a whole, we yet think that Mr. M'Clean's plan contains many of the main elements of a sound and judicious system of drainage. It is characterised by a well-devised system of intercepting sewers; in determining the situation and course of which a careful and elaborate study of the levels has evidently been made. These intercepting sewers generally follow the direction of the main thoroughfares, and avoid any extensive interference with private property."

In 1849 Mr. M'Clean received into partnership Mr. F. C. Stileman. The firm have been extensively engaged in the construction of Railways, Piers, Harbours, Docks, Waterworks, &c., including the South Staffordshire Railway and branches; the Birmingham, Wolverhampton, and Dudley Railway, with its double tunnel and high retaining walls, through the town of Birmingham; the Staffordshire and Worcestershire Canal Reservoirs, and the South Staffordshire Waterworks, which supply water from Lichfield at constant pressure to a population of nearly half a million, including the towns of Dudley, Walsall, Bilston, Wednesbury, Oldbury, Smethwick, West Bromwich, Tipton, Darlaston, Sedgeley, Brierley Hill, Bloxwich, and Burton-on-Trent.

In 1851 Mr. M'Clean was called upon to advise as to the practicability of introducing the English system of baths and wash-houses into Paris, and carried out extensive works at the sole expense of the Emperor Napoleon III. He was at the same time employed by a

* In our next volume we intend giving the drawings of Barrow Docks, including warehouses and other works, as there are many features of interest in the construction of these works.

body of English capitalists in reporting upon the means of procuring an additional supply of pure water for Paris.

After the death of the late Mr. James Walker, Mr. M'Clean was appointed Government Engineer to the Harbours of Dover, Alderney and St. Catherine's (Jersey), the Plymouth Breakwater, and the Shovel Rock Fort at Plymouth, the works of which had not been commenced. The foundations of this Fort are 40 feet below low-water.

He is Consulting Engineer to the Birmingham Canal Navigation and the Bute Docks, Cardiff; Engineer to the Surrey Commercial Docks, the Tottenham and Hampstead Junction Railway, the Bristol and Portishead Pier and Railway, the Cannock Chase and Wolverhampton Railway, the Furness and Midland Railway, the Ryde Pier Company, and numerous other public works in Great Britain. He is Consulting Engineer to the Lemberg-Czernowitz Austrian Railway and the South-Eastern of Portugal Railway, and has projected Railways through the Danubian Principalities for the purpose of connecting Austria with the Port of Galatz on the Danube, and also with Odessa on the Black Sea.

In the year 1855 he formed one of the International Commission, composed of eminent Engineers, representing France, Austria, Italy, Spain, and Holland, invited by the Viceroy of Egypt to visit that country and report on the practicability of uniting the Mediterranean and the Red Seas by means of a Ship Canal, the Barrage of the Nile, and other works. After a careful study of the country, Mr. M'Clean recommended that the proposed Canal should be made a Ship Canal, with water supplied from the Nile, instead of a Bosphorus, or Canal without locks, joining the two seas. In this opinion he was warmly supported by the late J. M. Rendel, Esq., F.R.S., and Charles Manby, Esq., F.R.S., the present Honorary Secretary of the Institution of Civil Engineers. It is now ten years since the date of this Report, and up to the present time the only communication between the two seas, although a very imperfect one, is by means of a Canal fed by the waters of the Nile.

In 1861 Mr. M'Clean was appointed one of the Royal Commissioners to examine and report upon the numerous plans submitted for embanking the River Thames within the Metropolis. The labours of the Commission were so successful that they completed an examination of all the plans submitted to them in 1861, and made their Report; and in 1862 obtained the Act for the Embankment of the River Thames from Westminster Bridge to Blackfriars Bridge.

In 1862 Mr. M'Clean acted as one of the Royal Commissioners to enquire into and report upon the best mode of embanking the Surrey side of the Thames within the Metropolis; and in July of that year, after the examination of numerous plans, their Report was published.

In 1863 Mr. M'Clean acted as one of the Royal Commissioners appointed to consider plans for making a communication between the Embankment at Blackfriars Bridge and the Mansion House, and also between the Embankment at Westminster Bridge and the Embankment at Millbank.

In 1865 Mr. M'Clean was appointed one of the Royal Commissioners to enquire into the origin, nature, &c. of the Cattle Plague; and in the same year, on the Royal Commission on Railways.

Mr. M'Clean became a Member of the Institution of Civil Engineers in the year 1839, and Member of the Council in January 1848; Vice-President in January 1858; and filled the office of President for the years 1864 and 1865. His address on that occasion attracted considerable attention by the views it set forth upon the enormous effects of engineering works in promoting the prosperity of the country. By a comparison (drawn from published returns of property and income) between the years 1815 and 1856, he showed that the striking improvement in the national resources during those forty years was mainly attributable to the Railway system, which, besides its obvious agency in facilitating transport and promoting the development of our mineral wealth, had afforded extraordinary encouragement to the investment and reproduction of capital, and had contributed largely to the establishment of the wealthy and intelligent middle class, who have lately done so much in educating and humanising the mass of their countrymen.

This address, containing other important and well-digested statements with regard to the vast and inexhaustible supplies of coal and iron in Great Britain, the progress of ship-building, and the construction of public works, was translated and read at the "Société des Ingénieurs Civils" at Paris, exciting much interest and approval.

His term of office as President was marked by the creation of the Benevolent Fund of the Institution, amounting to £26,000, in which useful project (originally suggested by F. J. Bramwell, Esq.) he took the warmest interest.

Mr. M'Clean is now in his 53rd year, and we trust that his valuable and useful life may long be spared.

A RECORD

OF

MODERN ENGINEERING.

1865.

ADDRESS.

It is with a well-assured confidence of still further success than the first two volumes received, that we now make this third issue of the "Record."

At the request of several of our subscribers, we have devoted the plates entirely to the illustration of the Metropolitan Main Drainage and the Thames Embankment, as being two of the most important engineering works of modern date. In consequence of the great mass of information to be introduced into so comparatively brief a space, it has been found necessary to make the drawings, in many cases, to a very small scale. The exactness of their execution, however, will enable the minutest details to be understood.

We have this year given a biographical sketch and photographic likeness of J. R. M'Clean, Esq., President of the Institution of Civil Engineers.

We beg to tender our most sincere thanks to J. W. Bazalgette, Esq., Memb. Inst. C.E., and Engineer to the Metropolitan Board of Works, for the use of the Contract Drawings, from which the plates have been prepared, and also for the general information which he has been at all times ready and willing to supply.

Abingdon Street, Westminster:
December 1865.

CONSTRUCTION OF HARBOURS, PORTS, AND BREAKWATERS.

THEORETICAL, CONTINUED.

IMPROVEMENT OF NAVIGABLE RIVERS, THE CONSTRUCTION OF TIDAL HARBOURS, AND HARBOURS OF REFUGE.

THERE being no two rivers on the surface of the globe precisely alike in every respect, as regards the operations of the engineer, it is consequently very evident that precise rules cannot be laid down applicable to all cases in reference to the improvement of rivers, the construction of tidal harbours on their banks, nor of harbours of refuge near their mouths. The engineer must not, however, suppose that because precise rules cannot be laid down with respect to the ever-varying aspects which hydraulic engineering presents to him, that he is to approach this the most difficult branch of civil engineering without a most careful study of the multifarious elements and varying aspects of nature with which he has to deal.

In studying executed works in connection with the improvement of rivers, whether for affording improved facilities for navigation, the drainage of the country constituting the basin of the river, or the reclamation of partially submerged land upon its banks, or a combination of all these objects, it will be very desirable to obtain plans and sections of the state of the river previously to the commencement of any of the works which have been executed, and to ascertain from reports of engineers and others, and by local inquiries, what were the precise objects which the several works were intended to effect. With the above information, and a careful examination of the several localities upon the ground, it will readily be perceived whether or not the objects contemplated in the execution of the several works have been fully or but partially realised. Works which have partially or altogether failed to answer the purpose for which they were intended, whether the failure has resulted in consequence of erroneous or doubtful theory in the design, or of imperfect workmanship, or defective materials in the execution, are frequently much more instructive than the most careful examination of works which have been most successfully carried out.

An engineer who carefully examines the various means which have been called into operation in the improvement of a river under given circumstances, and comparing its improved state with its condition before the engineering operations commenced, will be able to some extent to generalise and form rules for his future guidance. However reluctant engineers may be to prescribe rules to be applied in all cases which, even if possible, would have a tendency to cramp genius, retard progress, and reduce the profession to the handbook system, still it can hardly be possible but that in the great diversity to be met with in rivers, there are not also many points of resemblance; and if precise rules applicable to all circumstances cannot be laid down, at least some reliable principles may be deduced from several successful operations in this branch of engineering, as well as in other branches of the profession. It is better to have rules with exceptions than to have no rules at all.

The engineer in his treatment of rivers will find that his difficulties will increase as he approaches the sea. He must consequently enlarge his field of observation, and prepare to encounter still greater difficulties as he extends his operations into the deep sea, in order to form artificial shelter for shipping where no natural shelter exists.

The improvement of a river beyond the reach of the tide is a very different matter to the improvement of a tidal river, and requires a totally different treatment. Beyond the reach of the tide the question of navigation seldom if at all occurs; the more prominent points to be attended to being the reclamation of land on the banks of the river, if any such land exists; and the straightening, narrowing, and deepening of the watercourse in order the more effectually to carry off the land floods.

To fix the position of the banks of a river in order to train or direct and limit the space to be occupied by the bed of the river when improved requires very great consideration. If the enclosing or training walls are too far apart, leaving too much space for the flow of water, the reclaimed land will be curtailed in extent, and the value of the works diminished in proportion. The current would also be so much diminished, that banks or shoals would be formed between the training walls, and these shoals would change the direction of the current, and cause it to impinge upon one of the training walls, from which it would be reflected at an angle equal or nearly so to the incident or impinging angle, and would then strike the opposite bank at a point farther down the river.

It is this principle of the reflection of a body of water from any resisting substance at an angle equal to the angle of incidence, together with the nature of the geological formation of the country through which the waters flow, that causes streams and rivers to assume so winding a course as they almost universally do. It is therefore very essential that when a river is properly

trained within artificial banks in a straight direction, or with such easy regular curves as may be deemed under the circumstances of the case the most practical, that no obstruction be permitted to remain near one of the banks, such as a fallen tree, or the projecting remains of a slip of a portion of the bank. These obstacles would originate the deflecting currents which give the irregular form to natural streams and rivers, and these oblique currents act prejudicially in proportion to the narrowness of the stream and the weakness of the central current. Where the river is wide and the central current strong, the water deflected from the banks by any projecting obstacle will be met by the central current and carried off by it, and thus prevented from injuring the opposite bank.

The danger of leaving too little space between the artificial banks for the water of the river to flow off may be still more fatal than that of leaving too much. When the space for the flow of the water is too much restricted, the current would be so concentrated as to undermine and carry away the banks or training walls, the reclaimed land would be inundated, and the whole operations would be worse than useless. In laying out training walls, and assigning the space for the waterway of a river passing through an agricultural country, it will be necessary to take into the account the extent of the subsoil drainage of land which has already taken place, and which may hereafter be greatly increased, as these land drainage operations bring the rainfall due to the basin of the river much sooner and in far greater quantities down to the river than previously to the existence of land drainage. Soon after the rain falls upon the cultivated ground and pasture lands which have been under-drained, it finds its way into the drains, and so into the river, before evaporation can take place to any great extent; hence the increased quantity of water to be carried off by the river, and in a much shorter time than formerly. In embanking a river with the view of more effectually carrying off the land floods and of reclaiming land on the banks of the river, many important considerations will present themselves to the engineer. He has to provide for the discharge of a greater quantity of water in consequence of extensive drainage operations and other improvements. This he will effect by cutting off sharp angles, directing his training walls so as to give a regular *régime* to the river, and give greater velocity to the current by removing shoals and other obstacles deepening the bed of the river, and by concentrating the mass of the water in order to obtain an increased hydraulic mean depth, and consequently a more rapid discharge of water by an increased velocity. The description and quality of the materials of which the training banks are composed are not of so much importance as from where they are to be obtained, provided that there is a good supply of the necessary materials for arming or securing the exposed side of the bank from the action of the water. Stone, hard chalk, or brushwood judiciously applied by way of fascines, will answer every purpose of defence from the action of the current.

When practicable, the material for the formation of the banks should be taken from the river, by the removal of shoals and the deepening of the bed, and not from the land side, as deep excavations on the land side lessen the value of the ground reclaimed.

In reclaiming land on the banks of rivers passing through a flat alluvial country, and in some cases estuaries under tidal influence, much may be done by what is called warping up the land—that is to say, tracing out the site of the intended banks, and raising a low wall, over which floods are permitted to flow; and when the waters become tranquil inside the bank, the alluvial matter held in suspension will form a deposit which will gradually increase, and in proportion as the land proposed to be reclaimed will be raised, the bank will also be raised and strengthened. Some successful attempts have been made to reclaim land from rivers and estuaries under the influence of the tide by tracing out the site of the intended wall with a structure of brushwood, resembling a low closely-woven hurdle, with the upright sticks thrust well into the ground. In this way the deposit is retained, and the water allowed to flow off freely. This very simple and inexpensive plan deserves to be more extensively adopted. When successful, this plan obviates the very great difficulty which has frequently been experienced in completing the portion of wall in the space which had been left open until the remaining walls were completed.

When land is reclaimed from a river and left several feet below the top water of the stream, the land water must be got rid of by pumping it over the bank into the river by wind or steam power. This detracts very much from the value of the reclaimed land, and should, if possible, be avoided. Where there is a constant current in a river, there appears to be no great difficulty in so arranging machinery as to raise water over the bank by mechanical power derived from the river itself.

Whatever plan may be adopted for the improvement of a river, the reclamation of land upon its banks, or the more effectual drainage of low-lying lands, it is of the first importance to the engineer that he shall be in possession of an accurate survey, extending over the sphere of his operations and some distance beyond, laid down on a large scale, with a series of accurate levels on each bank of the river, with cross sections at intervals, which would depend upon the nature of the river-bed, as every irregularity in the bed ought to be minutely and accurately shown.

The National Survey has at length supplied the great desideratum of benchmarks, extending over the United

Kingdom, having reference to a uniform datum; and also tidal observations at several important points on the coast, reduced to the same uniform datum. All maritime works, and also all railway works, should for the future be referred to this uniform datum. The geological phenomena exhibited in railway cuttings and tunnels, and also by the foundations of river bridges and viaducts, would, by being referred to a uniform datum, enable geologists to generalise with greater accuracy than it is possible to do without such aid. The hydraulic engineer would also be enabled to generalise with greater accuracy and over a much greater extent of country, if all hydraulic works in the kingdom were referred to the same uniform datum.

There can be no doubt whatever that there will soon be a legislative enactment prohibiting the discharge of sewage from towns and villages into rivers or tributary streams; consequently the reclamation of waste lands upon the banks of rivers, or in any other eligible position, will afford a favourable opportunity of profitably disposing of the sewage, which doubtless must soon be disposed of otherwise than by polluting rivers and streams.

The improvement of rivers in which the tide flows, or in which it is desirable to bring the tide for the purpose of navigation, becomes a much more complex problem than the improvement of a river, where the question of navigation is of little if any importance, and where the influence of the tide is not felt.

A river in which there is a constant supply of land water, and passing through a country where the alluvial deposit carried into the river is very inconsiderable, the first consideration is how the power of this stream is to be turned to the best possible account in scouring out the bed of the river and in bringing up the tidal wave to the highest possible point, or to any required position, such as to a town, or to a proposed site for docks or ship-building slips. The waters of the river must be concentrated in order to increase its scouring power, and its mouth, when terminating in a tidal estuary, must also be so contracted and deepened as to increase the upward flow of the tidal wave. There are two modes generally adopted in the commencement of this process of confining the waters of the river and directing the inward flow of the tide into the same channel. One plan is to commence by throwing out jetties, or groins, perpendicular to the shore, from the banks at each side of the river, and extending towards the centre as far as the site of the proposed training walls. These jetties, or groins, are thrown out for the purpose of confining the current of land water and of tidal flow to a more central position; but principally to warp up land and produce a shoaling of the river banks to the extent required. These groins, however, have the effect, or rather defect, of forming holes in the bed of the river, which it is desirable to avoid, by giving to the stream an increased velocity in passing round the heads of the groins.

When the groins have been continued for some considerable time, and some progress made in silting up the spaces between them, their projecting ends are connected by training walls, which are low at first, so that the water may flow over and leave an alluvial deposit. These walls are increased as the land becomes silted up, and the enclosed position of the river becomes deeper by the partial concentration of its waters and by the greater advance inwards of the tidal wave. It is to be doubted whether the system of throwing out groins is a very judicious measure, as much time is lost and much expense incurred for very little real progress towards embanking a river for the purpose of improving the navigation.

Groins have been very efficient in collecting and retaining shingle on exposed coasts in order to guard against the inroads of the sea; but the analogy is not very close between the cases of collecting shingle rolling along a coast line and the quiet deposit of alluvial matter held in suspension in the waters of a river or estuary. It appears a more direct and a more economical mode of procedure to commence by low training walls in the first instance, and gradually to add to their height and stability as the nature of the silting up may determine,—the training walls being designed in such a manner as to be gradually widening out towards the sea, so that there may be no restriction to the influx of the tidal wave, in order to produce the greatest possible scour by the concentration of the ebb tide and the waters of the river. Much diversity of opinion exists upon the subject of the exclusion of tidal waters from a river by training walls, and converting into dry land space formerly occupied by water. It is argued that a great body of water is thus excluded which would be available for scouring out the channel of the river by the ebb tide; but it must be obvious that the water spread out upon the flat banks of the river and estuary would run out on the first or top of the ebb remote from the central position which it is desirable to scour out, and produce no beneficial effect in deepening the proposed channel. The scouring out of the narrowed or restricted channel is best and most economically effected by the land water, when that is in sufficient quantities; and as the deepening process increases, an increasing quantity would come up in the deepened portion of the river to compensate for the water which occupied the flat banks, and ran off at the early ebb without exerting any useful effect, whereas the water thus running off at the latter period of the ebb would be very efficient in its scouring power.

When the proposed improved navigation can neither be opened nor kept open by a combination of the above

methods, recourse is frequently had to the formation of a reservoir beyond the head of the navigation. These reservoirs are generally formed in a broad part of the river, and a dam constructed across it at the most convenient spot, for the purpose of impounding the water of the river to be applied to scour out the channel from the reservoir to the sea. In the wall of the dam several sluices are placed, which are drawn up to allow the escape of the water from the dam at the precise time of the ebb tide, when the current thus formed will act most beneficially in scouring out the channel. The time for opening the sluices will depend upon the length of the channel, as the whole of the impounded water should be expended before its influence is counteracted by the return of the tide at the mouth of the channel. Where river water cannot conveniently be impounded, a reservoir may be constructed and filled from the tide at high water and let off on the last of the ebb. By doubling the quantity of water employed in scouring out a channel the effect will be fourfold.

When an estuary has several channels, they ought when possible to be reduced to one, in order to concentrate the influx and reflux of the tide to and from the channel which it is intended to make navigable; and this is more imperatively necessary when, as is frequently the case, the tide flows in through one channel and passes out at another. This is a condition of things which, if not remedied, would neutralise every attempt at a successful improvement of a river estuary.

When all has been done that can be effected by means of groins, training walls, scouring out by tidal and river water by the adoption of river reservoirs, and impounding water from the high tide, recourse must be had to dredging. This is doubtless a tedious and an expensive process, but great improvements have recently been made in the efficiency of the machinery, and also in the economy of the operation.

There are many rivers or estuaries where the influence of fresh water is so small as to be quite unimportant. One advantage gained in this case is, that the alluvial deposits brought down by the river water would be reduced to a minimum, and when there is little or no material brought in by the flood tide the improvement of the channel is very much simplified. Little more can be done than the removal of sharp bends, giving a uniformity of breadth, widening out slightly towards the sea, and also giving a uniform *régime* to the bed of the channel as well as to its banks by the removal of shoals by dredging, if this cannot be effected by any other means.

When a river runs into a tideless sea, such as the Mediterranean, the Black Sea, the Baltic, &c., the navigation must be kept open by the fresh water current, which in several respects must have a treatment differing from that of a river where the action of the tide is an auxiliary power. The débris brought down by a river of this description is generally so great that a large delta is formed at the mouth of the river, such as the delta of the Nile, the Ganges, the Danube, &c.; and the delta being composed of alluvial matter, the river generally divides into several branches, and the velocity of the descending waters is diminished in proportion to the number of branches into which the river divides itself, and the natural consequence is that a bar or shoaling is formed at the mouth of each of these several branches. Having made choice (after a careful examination and consideration of all the circumstances of the case) of one of the many branches into which the parent stream has been divided, the branch selected for improvement will have one peculiarity which rivers running into a tidal sea have not—that is, a gradual extension of the delta, and also a bar, which is common to almost all navigable rivers, whether tidal or not. The improvement of the river being effected by training-walls cutting off sharp angles and circuitous bends, and by dredging if necessary, the next operation must be to get rid of the bar. This is effected by throwing out groins or training-walls into deep water on each side of the mouth of the stream. The space between the walls will depend upon the size of the stream; but the distance must be much smaller than the stream inland, so that the water may be sufficiently concentrated to remove the deposit from the bar. In some cases these walls are curved, and in other cases they are straight and converging towards each other as they approach the sea. Both these plans, under special circumstances, may possess advantages; but, considering that the delta is gradually progressing seaward, both plans at a future time may become embarrassing, as the curved walls would, if continued, curve back into the land, and the converging walls would meet if produced. The wall nearest to the prevailing winds should be carried considerably farther seaward than the other wall, as this arrangement would enable vessels the more easily to enter the river, and the projecting wall would give temporary shelter to vessels in stormy weather which did not intend to enter the river. This would also leave future projections of the walls, as the delta extended into the sea, to be directed according to the then circumstances of the case.

When an important river, in passing through a delta formed at its mouth, branches into a number of comparatively small streams, it may frequently be more advantageous to cut a canal from the river, or from one of its principal branches, into the sea, and, if possible, to reach the sea at a point where the progress of the delta seaward has ceased, or where its influence can be guarded against. This point would in many cases be an eligible position for a harbour of refuge; and if the navigation could be more readily and more economically

improved by lock-gates, raising the level of the inland navigation, there being an abundant supply of head water without the expense of storage, it would be an advisable course to pursue: that is, when it would not interfere with the drainage of the country.

There are also very frequently bars at the mouths of tidal rivers, as well as in the mouths of rivers running into tideless seas. The bars in tidal rivers are extremely difficult to deal with, since they are acted upon alternately and in many cases simultaneously by two opposing forces. The bar is formed by materials brought down by the river, and also of sand and shingle brought in by the tide. The position of the bar is frequently changed, and that in proportion as one or other of the conflicting powers prevail. These bars can only be removed by dredging or by throwing out jetties or piers; and to give the most useful direction to these structures requires an intimate acquaintance with the prevailing winds, the direction and velocity of the tidal currents, and the strength and nature of the waves to be resisted. Great constructive skill is also necessary to erect works which shall resist the action of the sea in an exposed situation.

HARBOURS OF REFUGE.

HARBOURS OF REFUGE, properly so called, must be available at all states of the tide, and as easily accessible in all directions of the wind as the nature of the circumstances will admit. In many cases, however, shelter may be obtained in tidal harbours; but as these can only be entered at or near the time of high water, vessels seeking such shelter must beat about for several hours until there is sufficient depth of water for them to enter. The danger which vessels incur whilst hovering about on a lee shore for several hours, in order to seek shelter in a tidal harbour, would seldom be risked by anyone who was able to keep to sea; consequently, such harbours are seldom resorted to for shelter in severe gales of wind.

Great Britain and Ireland, from their insular position and geological structure, possess a greater number of natural harbours than any other country; but, unfortunately, some of the most spacious, best sheltered, and most easily accessible, are remote from the principal lines of sea-going traffic.

In the selection of a site for the construction of an artificial harbour of refuge, several considerations must be attended to: not the least important of these must be a careful study of the wreck chart. The construction of a harbour of refuge, under the most favourable circumstances, being a matter of great expense, it is necessary to place this shelter as near as possible to the position where shipwrecks most frequently occur, in order that the greatest number of lives and the greatest amount of property may be saved.

It is scarcely possible to think or write upon the subject of harbours of refuge without being forcibly impressed with the consideration that the necessary shelter for the shipping of this commercial country should be in the hands of the Government of the country, and carried out at the expense of the public, as much so as it has to ensure the preservation of life and the protection of property by the civil power. The construction of harbours of refuge is a matter of too much importance in a national point of view to be left to private enterprise.

It unfortunately happens that the mercantile shipowners of the country are the greatest opponents to the construction of harbours of refuge, and these are the very parties who, at the first blush of the matter, might be supposed to be the strongest advocates for the most efficient protection for life and property at sea being provided at the public expense. Shipowners, however, seem to be perfectly indifferent about diminishing sea risks, or whether a ship ever arrives at its destination at all or not, as they take care to be fully insured. Their profits are derived from quick voyages, and they assert that "Breakwaters and harbours of refuge would be positive nuisances," which "lazy and timid captains would convert into skulking-places."

In addition to a careful study of the wreck chart, so that the harbour of refuge, when constructed, may be available for the greatest number of vessels in distress, the outline or contour of the coast must be carefully examined, also the proximity of building materials for the construction of the works, the nature of the anchorage ground about to be enclosed or sheltered, together with the strength of the waves to be resisted, the direction of the most violent gales of wind to be guarded against, the fetch, or greatest range of open sea in any direction, and the velocity and set of the tidal currents.

These matters are all highly important, and they assume so many different aspects, according to the varying circumstances of locality, that it is difficult, if not impossible, from any given number of individual examples, to deduce fixed laws applicable to all cases and in all situations. The greatest diversity of opinion exists among engineers upon the form which is to be given to the wall of a harbour or breakwater which is intended to neutralise or destroy the strength of the sea acting against any artificial structure. The great difficulty in determining the shape and the mass of an artificial structure to resist the violence of the sea under all circumstances is the very complex preliminary question of the nature and amount of the force which is to be resisted. This point being once decided, there would be no difficulty in determining the nature of the structure which would be necessary to resist the violence of the destructive agent brought against it.

For the purpose of arriving at something like approximate data, if absolute certainty be out of the question, waves have been distinguished into waves of the first, second, and third order, and attempts have been made to define the distinct action of these several waves, and from a knowledge of this action to determine the nature of the obstacle which would most effectually resist or divert the opposing force.

A wave of the first order is said to be a wave of translation or of progressive motion, generally assuming the character of a ground swell, undulating up and down, backwards and forwards, constituting a vast mass of solid water, moving as a whole in one direction with great velocity, and nearly as powerful at great depths as at the surface. When this ground swell arrives at the mouth of a river with a large bell mouth, and narrowing for a considerable distance inland—such as the Hooghly, the Severn, the Dee, and many others—it forms what is called a tidal bore. The tide, advancing with considerable velocity, is so much converged by the rapidly narrowing of the channel, that the water rises to a great height, and in rushing up the channel the top water tumbles over the lower portion of the flood, and forms an advancing wave of several feet in height, and nearly perpendicular.

This peculiar phenomenon can only occur in a channel of the peculiar formation alluded to, and with a flood tide; but in narrow straits, and even in open seas and near projecting headlands, somewhat similar waves are formed, which are not in all cases so easily accounted for. These oceanic peculiarities are generally known by the term *races*, or *roosts*. They are formed frequently by the meeting, directly or obliquely, of tidal currents, or by a strong gale of wind or a heavy ground swell being met by a strong tidal current. These races or roosts are very formidable to shipping, but seldom occur where harbours of refuge would require to be constructed; indeed, in some cases where these races or even strong tidal currents pass the entrance to a bay or the mouth of a river where a breakwater has been constructed, considerable protection may be given to the work by the direct ocean wave being retarded, and its power partly neutralised by the passing current or race.

A wave of the second order is called a wave of oscillation, and is not supposed to have any progressive motion, or to act with percussive force against an upright or a nearly upright wall. This oscillating wave must, however, exert a pressure against a vertical wall equal to the unbalanced statical pressure due to the height of the wave.

This description of wave is changed into a wave of the third order, or a wave of percussion, when it comes into comparatively shallow water upon bars at the mouths of rivers, on a shelving shore, or in any position where the depth of water is not much greater below the hollow of the wave than the height from the hollow to the crest of the wave. When the hollow of the wave is retarded by friction against the ground, the top tumbles forward, is changed into a mass of broken water, and rushes forward with a velocity proportioned to the height and length of the wave, or to the mass of water contained in it. A gale of wind will also doubtless change an oscillating wave into a wave of translation, exerting a percussive force against an opposing obstacle. A ship running before a gale of wind, for example, will frequently be struck on the stern by a wave which, to effect this, must have been travelling at a greater velocity than the ship.

The nature and the action of waves are subject to so many circumstances and influences, that the attempts made by experimenters and theoretical reasoners to classify and define the peculiar action of each class have only partially succeeded in establishing any satisfactory results; but the nature of the subject scarcely admits of accurate experiment. Mr. Stevenson's marine dynamometer has been applied for the purpose of ascertaining the force of waves against a given area of any resisting obstacle; and if this instrument has been accurately constructed and judiciously applied (and there is no reason to doubt either), the impinging force of every class and description of wave against an upright wall is very considerable.

The greatest recorded pressure or force of wave is $3\frac{1}{2}$ tons on a square foot of surface.

The diversity of opinion existing amongst engineers upon the amount of wave force to be resisted under any given circumstances, has very naturally led to considerable difference of opinion upon the form of wall most suitable for a breakwater, and the mode of construction best adapted to resist the violence of the sea. The forms of breakwater which have been advocated and adopted in several localities may be included in the three following classes:—1st, The vertical or nearly vertical wall, built up from the foundation. 2nd, The flat slope formed by the action of the sea upon stones of various sizes dropped into the sea from staging constructed over the site of the work. 3rd, A flat sea slope up to a point eight or ten feet below the low-water line, and upon the extended base of loose rubble thus formed as a foundation, to construct an upright or nearly upright wall of the required height. This latter is the most general form adopted, whether from choice or from the demand of controlling circumstances.

The vertical or nearly vertical wall has many advocates and many advantages. It requires much less material than the flat slope, and when building materials have to be brought from a considerable distance, the adoption of the upright wall almost becomes no longer only optional.

An upright wall in deep water, being acted upon

by a wave of oscillation, receives little more than pressure from the mass of water acting against it; but an upright wall built upon the top of a long slope receives the full force of a wave of translation, the wave having been changed by coming in contact with the slope, when it breaks and rushes up with a destructive energy against the upright portion of the wall.

The upright wall resists the shock of the waves by the inertia of its mass, the superior workmanship so combining the whole structure as to make all its parts effective in resisting any shock that may be brought against it; whilst the materials deposited loosely on a flat slope, however large the blocks of stone or concrete may be, have no mutual support, and the wall is consequently liable to be destroyed in detail.

An upright wall will have a back-wash from the wall seaward, which will have a tendency to draw away the materials from under the foundation, unless founded upon a rock. This is, however, very easily remedied by depositing a few large blocks at the foot of the wall, which will form a sufficient protection, as there is very little motion in the water at considerable depths below the surface. The sloping wall receives very nearly as much damage from the back current as from the advancing wave.

When a vertical wall on the top of a flat slope is adopted, the intention frequently is to make the work serve the double purpose of a breakwater and a harbour, or a harbour of safety and a harbour of commerce. In this case a parapet is carried up, to prevent the top of the wave from passing over on to the roadway, which is formed on the top of the upright wall, for landing and transporting merchandise. The interior slope in this case is kept as nearly upright as possible, so that vessels may lie along the inside of the wall to load and unload. But when a breakwater is formed solely for the purpose of shelter, and consisting of loose stones dropped into the sea and the slopes formed by the action of the waves, small stones, and even the débris of the quarry, ought to be deposited along with the large blocks, so that the action of the waves would force the smaller material into the interstices of the large blocks. This is a matter of considerable importance, as cavities left in the wall would be filled with air, and, acted upon by the advancing wave, would blow up the paved surface of the wall, and form a dangerous breach. In constructions of this description, the top of the wave is permitted to pass over the wall; and that this may be effected without damaging the wall, it is necessary that the top of the work should be paved with large blocks, closely fitted and dovetailed or joggled together, and this paving should be carried as far as possible under low-water on each side of the wall.

Upright walls have hitherto been very expensive, in consequence of preparing the foundations and setting the stones by the application of the diving bell. This is not only an expensive, but also an extremely slow mode of construction, and it may easily be superseded by cheaper and more expeditious plans.

To induce the Government to take up the subject of the construction of harbours of refuge on an extensive scale (from which the authorities appeared to be deterred by the expensive nature of the works), various plans and modes of construction were proposed, principally for floating breakwaters. This mode of construction has, however, been justly discarded, for many reasons. If the floating mass be of sufficient magnitude and sufficiently deep in the water to constitute a quiet harbour, the strain upon the anchorage must be very great; and should the floating structure ever give way, it would be under the heaviest storm, at the very time when it is most wanted, and when the drifting mass would carry all the shipping to leeward of it upon the shore. When the floating structure is of a light description, and not very deep in the water, a ship in the enclosed space would have little more protection than it would derive from being anchored to the leeward of another ship.

A mode of constructing breakwaters with vertical walls was also proposed, with the view of superseding the slow and expensive process of the diving bell, by placing the stones or blocks of concrete in position by guide rods passing through the blocks.* This system of construction may now be carried to a very successful result, in consequence of the recent improvements in the manufacture of Portland cement. These improvements are so great, that blocks of cement concrete of almost any size may be made to resist the action of the sea as well if not better than any description of stone except granite.

Blocks of cement concrete may be used up to a weight of one hundred tons. A block of this weight would measure about twenty feet long, twelve feet broad, and eight feet thick, and may be deposited as follows:—The block to be formed in a mould placed in such a position above high-water that when the concrete has been sufficiently consolidated to admit of being removed, and the block on the bottom of the mould launched into the water, being previously hooked on to two travellers by four lewises, two to each, or other secure and convenient mode of attachment; and when the block is launched into the water it loses more than half its weight, and consequently each traveller would have less than twenty-five tons to bear. As the top of the guide rods would not be higher than low water, their position would be marked upon the platform, in order to stop the traveller at the exact point, and the holes in the blocks should be formed with a bell mouth at the lower side of the block, so as easily to catch the head of the rods. A block of the above dimensions would

* See *Mechanics' Magazine*, July 17, 1863, p. 508.

probably require an inconvenient time to consolidate sufficiently to bear removal; but a block of the same length and breadth, and half the thickness, weighing about fifty tons, would be easier handled, and would consolidate much sooner than a block of double the thickness as above described. Two rows of such blocks placed parallel to each other, and about twenty-five or thirty feet apart, with a hearting of chalk or rubble stone, would form a cheap and very efficient breakwater, and capable of being rapidly constructed. Where chalk abounds it will form an economical and efficient hearting, and being thrown into the water as the outside walls are being carried up, it would become a very solid mass; and if water is excluded by caulking or cementing the joints of the blocks, chalk will form a solid, inert, efficient hearting. The wall would be carried up about ten feet above high-water, and the chalk hearting covered over by massive blocks in an arched form, so that the top of the wave could pass over and fall into the harbour without being able to propagate a wave.

The iron rods passing through the blocks (which would be well coated with white lead) would give great strength to the horizontal joints. Additional strength might also be given by forming raised portions on the upper bed of each block and corresponding hollows on the lower bed of all the blocks, and thus effectually joggling all the horizontal joints; and by a similar process the end vertical joints might be secured, and thus the whole of the blocks would be united into one mass to resist the shock of the sea.

Another mode of forming the outside portions of a breakwater wall by blocks of Portland cement concrete is as follows:—

Blocks of cement concrete will be formed twenty feet long, twelve feet broad, and about four feet thick, weighing about fifty tons, and easily handled by being attached to two travellers.

These blocks would be placed nearly on end, upright or nearly so, facing the sea, and placed in the wall at an angle of about seventy-five degrees. When the block is brought over the position in which it is about to be placed in the wall, the front end of the block will be lowered into its position and allowed to slide down gradually upon the block previously placed in position, and allowed to find its bed in the sand by its weight. In order to guide the blocks into a symmetrical position in the wall, and also effectually to combine the blocks together, a projection must be formed on one side of each block, running along the whole length of the centre of the block, about eighteen inches on the base, and about six inches high, with the corners rounded off. A groove would be formed in corresponding blocks to fit on to the projection of the block previously laid, and in this way the blocks would be tongued and grooved together, which would render the operation of placing them very easy, and also combine into one homogeneous mass the whole wall. A coating of neat cement would be placed on the inside of the groove before the block is lowered into its place.

In forming blocks of cement concrete, the faces and ends of the block, which, when placed into the work, will be subject to the wash of the sea, may, in filling the mould, be composed of a greater proportion of cement than the other portions. Two lengths of twenty-feet blocks would, in almost all cases of the construction of breakwaters, reach from the foundation to the level of low-water. The end joints of the blocks would also be tongued and grooved or joggled together, and the joints would be broken by varying the length of the blocks.

One very great advantage in a construction such as that just described is, that the scaffolding for the travellers to move upon, in depositing the blocks, need only to be a few yards in advance of the finished work, and consequently never presenting more than three or four piles to the action of a storm likely to damage works in progress.

The first point to be considered in the selection of a site for the construction of a harbour of refuge is unquestionably to ascertain the position where it is most wanted, and where it would, if constructed, effect the greatest amount of good.

Good anchorage or holding ground is also essentially necessary, and without which a harbour that would protect a ship from the violence of the waves, but not enable her anchors to hold her against the strength of the wind, would be altogether inefficient. It is also essential that a harbour of refuge should be easy of access for shipping at any time of tide, and in any state of the weather, or with any direction of the wind.

A deeply imbedded bay, where there is a sufficient depth of water and good holding ground, offers an eligible site for a harbour of refuge, particularly where a single detached wall, with an entrance at each side of the bay, would afford sufficient protection to a large deep-water area. The wall should be slightly convex towards the sea, in order to break to some extent the direct action of the waves by deflection, but not so much as to throw a heavy sea across the entrances to the harbour.

In some conformations of coast it would be more advisable to throw out a wall from each side of the bay, and to place the entrance to the harbour in the centre. Unless the mouth of the bay is too wide, it would be better to place the walls as near as possible to the mouth of the bay; for if the bay converge rapidly, heavy seas carried into it would become, by concentration, much more powerful as they advanced into the bay. The width of the entrance should bear some relation to the extent of the area of anchorage ground enclosed, and should, in general, admit of three sailing vessels passing

in at the same time. From two to three hundred feet would, under ordinary circumstances, be a sufficiently wide entrance. If too wide, the harbour would not be sufficiently tranquil; and if too narrow, the current would be inconveniently strong for ships to pass readily through the entrance.

It is sometimes convenient to throw out a wall from one side of a bay in order to form a breakwater, and the entrance round the head of the wall would probably be half the width of the bay. The principal points to be attended to in this case are so to design the position of the wall that vessels can readily get behind it for shelter from whatever direction the storm may blow, and to guard the anchorage ground from the greatest fetch or longest stretch of open sea. It is of more importance in a harbour of refuge that the access to it should be the best possible, even if the exit be somewhat inferior. To leave an opening in the wall at considerable expense, for the purpose merely of an exit for vessels, may prove to be a useless expense, and considerably to impair the stillness of the water in the harbour.

Where natural shoals exist in positions where harbours of refuge could be usefully placed, advantage should be taken of these favourable circumstances, which would greatly lessen the expense of construction, and also occupy a dangerous reef upon which frequent wrecks may have taken place.

Much useful information may be obtained with reference to the strength of the sea at certain depths, and also as to the existence of a ground swell, by careful study of the nature of the deposit on the bottom. The existence of a light alluvial deposit of mud proves the absence of ground swell, and also a quiescent state of the water at the depths at which such light materials are found.

Much diversity of opinion exists upon the subject of the silting up of harbours, and unnecessary alarm has been caused by the extreme views which have been held. The question is a very simple one. On an alluvial or chalky coast, where there is a considerable quantity of matter held in suspension in the water which is admitted into the harbour, the matter held in suspension will fall down and form a deposit in exact proportion to its specific gravity and to the quiescent state of the water, without any reference whatever as to whether the harbour has been enclosed from the open sea or formed by an excavation in a low-lying district of land. On rocky iron-bound coasts, where there is hardly any matter held in suspension in the water, deposit in harbours can hardly exist.

Harbours of refuge may be excavated where there is a flat projecting point of land—such, for example, as Dungeness—much cheaper and more expeditiously than a harbour of equal extent can be enclosed from the sea. At Dungeness there would be an abundant supply of shingle for the formation of cement concrete blocks for the construction of the walls of the harbour, and for throwing out jetties at the entrances to prevent the shingle from travelling along the shore and filling up the entrances to the harbour.

There are so many elements which enter into the problem of the selection of a site for the construction of a harbour of refuge that it becomes quite clear the question can only be decided by a compromise—a balancing of favourable and unfavourable circumstances; and when it becomes essential for harbours of refuge to be fortified, the subject becomes still more complex, and requires the combined talent of the civil and the military engineer and of the experienced sailor.

PORTS AND HARBOURS.

PORTS and HARBOURS may in a general way be defined as places affording a safe shelter for ships, or to which ships resort for the purposes of trade. But the subject in its widest application has so many adjuncts and ramifications as scarcely to admit of a distinct classification, and an attempt to give an exact logical definition of these terms would appear more pedantic than useful. The term Port or Shipping Port has, however, a more extended signification than the term Harbour, as it includes all the jetties, quays, docks, both wet and graving docks, building slips, and all the various appliances necessary for the expeditious and economical working of the import and export trade of the port.

These various appliances generally grow up in proportion to the increase of the trade, and the nature of these auxiliary arrangements are, or ought to be, in character with the particular description of trade connected with the port. In general, the limits of a port extend as far as the jurisdiction of Harbour Masters extends, in reference to the exercise of their authority in arranging and berthing ships, but perhaps this extent is defined still more accurately by the area over which shipping dues can be levied. The extent of these areas are in general fixed by custom, by charter, or by legislative enactments, and seldom extend beyond the limit where some benefit or prospective benefit is conferred—such, for example, as shelter from storms, improved navigation, the convenience of mooring chains, &c. Ports are generally supplied with moorings for ships to make fast to instead of casting their anchors, as anchors will only hold in the ground when drawn in one direction. It is usual, therefore, to place anchors on each side of the river, and connect them by chains, and to the centre of these chains longitudinal chains are attached, to which mooring buoys are made fast. Thus a great expenditure of chain is necessary in order that the strain upon the anchors shall act in the direc-

tion in which an anchor can effectually resist a strain. In order to secure an attachment to the ground without so great an expenditure of chain, masses of iron or stone have been sunk a considerable distance into the ground, to which chains and mooring buoys are attached. Screw moorings have recently been invented, and brought into extensive use. The screw mooring is composed of a bar of malleable iron, the lower end formed as a cutting or gimlet point, up to the full thickness of the rod or shank of the mooring. Above the tapering point is placed a cast, or malleable iron screw, the area of which will be made proportionate to the nature of the holding ground into which it is to be placed. This screw can be inserted into any kind of ground with the exception of rock, and the depth to which it is generally screwed down is from eight to eighteen feet below the bed of the anchorage ground.

This system of mooring vessels in a port is much more efficient and more economical than any of the systems previously in use, and as the chains are up and down to the buoy, anchors cast near them are not interfered with.

According to the extent and importance of a shipping port will be the amount of accommodation for loading or unloading cargo at quays, jetties, or in floating docks, and for depositing cargo in bonded stores until wanted for consumption, for transportation into the interior of the country, or for reshipment for exportation. Ports are also frequently supplied with extensive graving docks, for the careful examination and, if necessary, the repair of vessels of every description which visit the port.

When the port is a river improved by the several modes above described (such, for example, as the Clyde at Glasgow, and many others), much (and in some cases the whole) of the work of loading and unloading is performed at quays or river walls. Great improvements have recently been made in loading and unloading cargo by steam cranes, and more recently cranes worked by hydraulic pressure have been introduced by Sir William Armstrong. In many cases steam answers very well, and where coal is cheap is not very expensive. But where a line of cranes is very much extended along a river wall there is considerable difficulty in keeping the long steam-pipe which conveys the steam to each crane sufficiently well clothed to prevent the condensation of steam in the pipe. Another inconvenience, and also a source of considerable expense, is that the steam must be kept up in the steam-boiler, and also in the whole of the distributing pipes, at the required pressure when there are but few of the cranes at work, and these only occasionally.

When there is an abundant supply of water at high pressure, cranes can be worked much more economically by hydraulic pressure than by steam. The pressure or motive power is ready to be turned on at any moment, and for any length of time, and there is no loss or inconvenience whatever in connection with the application of water power in working cranes, care being taken to keep the pipes conveying the water sufficiently low in the ground to be beyond the influence of frost in winter. When the hydraulic cranes are not at work there is no expense incurred in keeping the power in a state of preparation for work, as is the case when steam is employed.

When there is no accommodation for loading and unloading cargo in a port, but on an extended river wall, and when the breadth of the river will admit of it, great additional berthing space may be attained by throwing out jetties at right angles to the river wall, and each of these jetties may be made to accommodate one or two vessels at each side.

These resources being exhausted, the next economical mode of obtaining berthing, or quay space for loading or unloading cargo, is by the formation of wet docks, projecting from the river inland. These docks, in their simplest form, have no entrance gates to retain the water at a uniform height, irrespective of the rise and fall of the tide, and in general the vessels will ground alongside of the quays at low tide.

The cheapest description of wet docks are those which are constructed without gates or upright walls. The sides of the dock are allowed to take the natural slope of the ground, and the slope is protected when necessary from the wash of the water by pitching or otherwise, and at those points along the sloping sides of the dock where a ship would be laid alongside for the purpose of being loaded or unloaded, short timber stagings are formed by driving piles into the sloping sides of the dock, presenting an upright face, against which the vessel is berthed, for the purpose of being loaded or unloaded. This is a very cheap expedient for gaining an increase of space for berthing ships, and has this very great advantage, that at any time perpendicular walls may be substituted for these temporary stagings, and entrance gates added.

In the construction of docks with gates, the first point which requires consideration is the direction of the entrance into the dock. When the river with which the dock entrance is connected is too narrow to swing a ship at right angles to the river, the entrance should point at an acute angle against the flood tide, so that vessels can enter with the flood tide, and those leaving the dock would pass out by the first of the ebb.

When dock entrances are placed at right angles or nearly so to a river, many points of considerable importance require to be attended to. When there are many vessels to be passed out of and into a dock in one tide, it is very important, under any circumstances, but more particularly in narrow rivers, or confined entrances from the sea, to form deep recesses or fore-bays at the outside of the exterior dock gate, in which vessels would be sheltered from the influence of the tide, and be ready to

be drawn into the dock at any time of the tide. In some cases a tidal entrance basin or extensive lock has been adopted with great advantage. When there is a sufficient depth of water over the sill of the entrance locks to admit of the class of vessels frequenting the dock to pass into and out of the dock two hours before and two hours after full tide, a great number of vessels may so pass in both directions in one tide.

When dock entrances, from local circumstances (which more or less affect all extensive works), cannot be placed in the most advantageous position, recourse is had to the use of dolphins or clusters of piles driven in such a position as to prevent vessels from being swung round by the tide at right angles to the dock entrance.*

It is not too much to say that there is no branch of the profession of a civil engineer so much dependent upon local circumstances as the construction of docks of every description, and the various appliances connected with them. The requirements of a port must first be taken into consideration—not only the present and immediate ones, but the prospective wants consequent upon the expected increase of trade.

It is a general mistake to design works capable of meeting the present wants of a port, and to place these works in such a position that enlargements cannot be carried out to meet increasing demands for space without the destruction and rearrangement of portions of the existing works.

When the wants of a port have been ascertained, the nature of the trade fully understood, together with a knowledge of the class of craft employed or likely to be employed in a more advanced state of trade, the most economical, and at the same time the most efficient, means to satisfy these wants must next be considered. Much will depend upon the situation in which the proposed works are to be constructed. If the intended work simply consists of a dock excavated in moderately favourable soil, and beyond the influence of water unless that of land springs, the whole operation becomes extremely simple, the lock-gates being the only work of importance requiring the exercise of judgment and care.

When the docks are to be constructed at or near the mouth of a river, upon a site partly reclaimed from the river or estuary, the subject probably assumes its most complicated form, and a careful examination of the geological structure, not only of the immediate site of the works, but for a considerable distance round the proposed site, becomes indispensable; the strength and set of the tide must be accurately ascertained at several stages of the flow and ebb; accurate borings must also be made over the whole area of the proposed site of the works, and some distance beyond. The situation and amount of deposit, and the nature of the materials of which it is composed, must be ascertained. In many cases the place from which the deposit has been brought may be ascertained from its composition. Tide-gauges should be established in several places, and careful and simultaneous observations registered, from which useful deductions may be drawn. The quality of the materials which are available for the construction of the works becomes an important subject of inquiry; and the nature of the design, both in plan and section, may be made to depend upon the materials available for the construction of the works.

The selection of a site for docks becomes a matter of much more importance as the works are more or less affected by the tidal and river currents; and the works, if properly placed, will, by skilfully directing the ebb and flow of the tide, assist in maintaining the channel in the most efficient state. It is absolutely necessary, therefore, that the most minute phenomena of the locality be carefully studied for a considerable time before any definite plan can be adopted with any chance of arriving at a satisfactory result.

In the construction of docks, where the area of the works has partly or altogether to be reclaimed from the river or estuary, the expensive and difficult operation of coffer-dams must be resorted to—that is, according to the present general system of hydraulic engineering practice. That something more scientific, more economical, and much more rapid in execution than the present clumsy, tardy, and expensive coffer-dam cannot be introduced into practice, does not reflect much credit upon the engineering genius of the age. Two rows of piles driven into the ground, about five or six feet apart, connected by iron bolts to keep the rows of piles together, and filled in between by a heavy mass of clay resting on a narrow base to drive them asunder and to make the dam water-tight when that can be done, appears to be a very clumsy contrivance.

When a coffer-dam has to be constructed on a rock formation, for the purpose of removing the rock to deepen the site of a proposed dock, the operation is sometimes successfully performed by throwing clay into the water, marking the outline site of the dam, and in this accumulation of clay piles are driven and connected together so as ultimately to become a stable structure. But unless a dam of this construction is intended to be used in some of the subsequent constructive works, it may be questioned whether rock, under ordinary circumstances, may not be removed more economically by blasting under water, with some assistance from divers.

To construct a coffer-dam on a rock formation, and in a rapid stream, for the purpose of preparing the rock for the pier of a bridge (or for any purpose connected with dock construction), and consequently constructing the pier in the dam, the operation becomes a very difficult

* Much valuable information on the subject of dock entrances (illustrated by reference to the Port of London) is given in a paper by John Baldry Redman, M. Inst. C.E., and published in the *Transactions of the Institution of Civil Engineers*, vol. vii. p. 159.

one. In this case the most likely way to ensure success is to construct the whole of the timber-work of the dam on the shore of the river of the form or contour of the rock, and care must be taken to make the principal timbers as near as possible conformable to the ascertained form of the bottom. The dam must consist of a double row of timber framing, five or six feet apart, with a cut-water to point up stream; and in addition to the principal timbers or skeleton of the dam, two rows of narrow sheeting piles, grooved and tongued together, would be arranged all round in connection with the stringers of both the frames of the structure, and when the frame-work of the dam is secured in its place, the sheeting-piles will be driven down to conform as nearly as possible with the uneven surface of the work, and by attaching felt or other soft substances to the lower ends of the sheeting piles, a partially tight dam would be secured, and would easily be perfected by clay puddle.

Various modes have been proposed to supersede the use of coffer-dams in the construction of quay or river walls, such as driving cast-iron piles of an **H** form into the ground a sufficient depth, and about five or six feet apart, and filling in the spaces between the piles with granite slabs. The piles are tied back with malleable iron rods to land ties and to each other when employed in the construction of a jetty.

It has also been proposed to drive a row of close cast-iron sheeting piles to a sufficient depth, to guard against any subsequent scour of the ground in front, the tops of the piles being driven to the level of low-water. The material is then removed by a vertical dredger from behind the sheeting piles to any required depth or breadth; and as this excavation would be performed by a dredger moved in every required direction by a traveller placed upon a horizontal platform, the ground would be dredged out to a perfectly level surface prepared for the foundation of the wall. The foundation of the wall would be constructed of large blocks of cement concrete, or of blocks of hard bricks built in cement. These blocks, whether of concrete or of brick, would have two holes formed in each block, in a given position, and the blocks lowered into the foundation of the wall upon guide rods of malleable iron passing the holes in the blocks. The guide rods would be placed in their relative position by being screwed into the intersections of longitudinal and transverse bars of iron, or into a framing of wood. The blocks used may be of very large dimensions, so that the stability of the work does not, as in the above case, depend upon the durability of the iron.*

Lock gates are generally constructed of iron, both framing and covering; but in some cases the framing only is made of iron, and the covering is composed of timber of good quality, generally teak, and the gates in all modern constructions are opened and shut by hydraulic machinery. This application of hydraulic machinery, however, cannot be economically applied for opening the lock gates, unless in cases where the whole of the work of the dock is also performed by the same appliances.

In some situations, great care is necessary to prevent dock retaining walls from being forced inwards, in consequence of the pressure of the ground behind the walls. Much may be done to prevent this by good drainage of the soil, and by punning; and in some cases this tendency is guarded against by throwing out counterforts behind the walls, and connecting these counterforts by segmental arches, presenting the convex side to the mass of earth to be retained.

The great perfection to which cement has recently been brought will probably, at no distant date, enable docks and other maritime structures to be formed of cement concrete at a much cheaper rate, and much more expeditiously, than by the use of stone. Cement concrete may be formed in mass in still water, either fresh or salt, as it will rapidly consolidate in water when not exposed to a current. It may also be formed in mass in air as well as in water, by depositing it in layers, and uniting the several layers by indents or channels, which would combine the whole mass effectually together. Cement concrete may also be used in blocks, but not so expeditiously as when used in mass, as above described. Either of the above modes of construction would be much more economical than walls faced with stone, and backed with brickwork or common concrete, and equally durable, as forming a more homogeneous mass.

When a dock wall, exposed to the action of the sea, is composed of roughly-dressed stones of considerable size, but not built so as to exclude water from penetrating into the body of the wall, it is necessary to form a clay puddle inside of the portion of wall which is nearest to the sea, and this core of clay should extend downwards into the soil on which the wall is built sufficiently far to prevent water leaking out from the dock into the sea, which might otherwise take place when the water is higher on the inside of the dock wall than on the outside of it. When this precaution is not taken, the constant rush of water, even in small quantities, but with considerable force, into the interior of the wall, will wash out the hearting, and in some cases blow up the pitching of the roadway, and also destroy the internal upright facing wall of the dock. As considerable breadth must be given to the dock wall, probably fifty or sixty feet, in order to accommodate the traffic of loading and unloading by carts or double lines of tramway, there will always be sufficient mass to resist by its inertia any force which may be brought against it; still, every means must be taken to guard

* See *Mechanics' Magazine*, 1863, p. 508.

against the constant operation of apparently slight but insidious causes operating to the destruction of the wall in detail.

Graving docks are intended for the examination of the hulls of ships, and also for their subsequent repair when that proves to be necessary. Ships may also be built in graving docks, and when completed, the water is let into the dock, and the vessel is floated out without the application of an expensive apparatus usually employed in launching ships. Graving docks are occasionally connected directly with a navigable river, but more frequently they open into a wet dock. They are supplied with one pair of gates only, and vessels are floated into the dock when the water is of sufficient depth over the dock sill; the gates are then shut, and the water is pumped out by steam power. Previous to the admission of a vessel into the dock, a line of blocks is laid along the centre of the bottom of the dock; and as the water is lowered by the application of the pumps, the keel of the vessel rests on the line of blocks, and, to keep her in an upright position, stays are placed against the sides of the ship, and resting in steps which have been formed in the sloping sides of the dock for that purpose.

Caissons are also frequently employed to shut the entrance to wet and dry or graving docks. They are of two kinds—either in the shape of a vessel, swelling out in the centre, to resist the head of water pressing against them, or of a rectangular form. In the former case, the ends of the caisson are made to fit into grooves formed in the masonry at each side of the entrance to the dock. These grooves have a considerable batter, and when the caisson is floated into the entrance, and the ends placed into the grooves, water is allowed to flow into the caisson to sink it, when it becomes tightly fitted into the grooves so as to become water-tight. When this description of caisson is required to be removed for a vessel to enter or to leave the dock, it must be pumped out and raised in order to clear the grooves—turned and floated away in order to clear the entrance. In the case of the rectangular caisson, when required to be removed, it is drawn into a recess formed in one side of the dock entrance. The caissons are useful as bridges when fixed in position, and they possess some advantages over gates.

In the construction of graving docks, it is necessary to pay particular attention to the stability of the foundations, not only of the walls of the dock, but also of the floor, upon which the whole weight of the vessel rests when the water is pumped out of the dock. Springs are frequently met with in excavating for the construction of graving docks, and as the source of these springs may be at a considerable elevation, if confined would produce great hydraulic pressure. It is necessary, therefore, to collect all these springs into drains, and to lead these drains into side drains or culverts, terminating at each side of the dock, near its entrance, in a vertical pipe or culvert, in which the water will rise and flow out at high-water, and thus the hydraulic pressure tending to blow up the bottom or floor of the dock, will be reduced to the known height from the bottom drainage to the overflow, and this pressure can be amply provided against by the weight of the flooring blocks and the concrete under them.

IMPROVED SYSTEM OF FORTIFICATION.*

As civil and mechanical engineers have recently effected such gigantic improvements in guns and gunnery, and as the practical part, at least, of fortification is intimately connected with the profession of the civil engineer, we make no apology for publishing the following new system of fortification.

The art of war can lay claim to great antiquity. It may almost be considered as coeval with the existence of the human race—at least with the formation of mankind into tribes and small communities. It may be divided into two leading branches—the *attack* and the *defence*. Wandering tribes, it is true, may have found it necessary to defend their habitations from the incursions and depredations of wild beasts by some kind of enclosures previously to the hostility of man against his fellow-man.

The operations of defence would necessarily vary according to the alterations or improvements in the modes and weapons employed in the attack. Man, who has been defined as a 'tool-making animal,' has supported that character as much in the formation of weapons of destruction as in making implements of peaceful labour; and there is no period in the history of the human species in which so much ingenuity has been displayed in the manufacture of weapons of destruction by the 'tool-making animal' as at the present period.

The battering-ram of the ancients, worked by manual labour, has been, by the invention of gunpowder, formed into a powerful weapon, capable of carrying death and destruction to considerable distances; and this power,

* By Alexander Doull, C.E. *A few copies of this paper were circulated privately in* 1861.

and the distance at which this modern battering-ram, the cannon, can be effectively used, appears to be rapidly on the increase.

The fundamental principles of attack and defence must be very nearly the same in all ages, and among all races and tribes of men. One party, whether the weaker or the more cautious and prudent, places itself in a position of security to prevent being taken by surprise by an adversary, and, if necessary, to repel an attack.

There are advantages peculiar to both systems of attack and defence, and these advantages appear at one time to favour the defence; and then some improvement in the mode of operation, or in the weapons employed, turns the scale in favour of the attack.

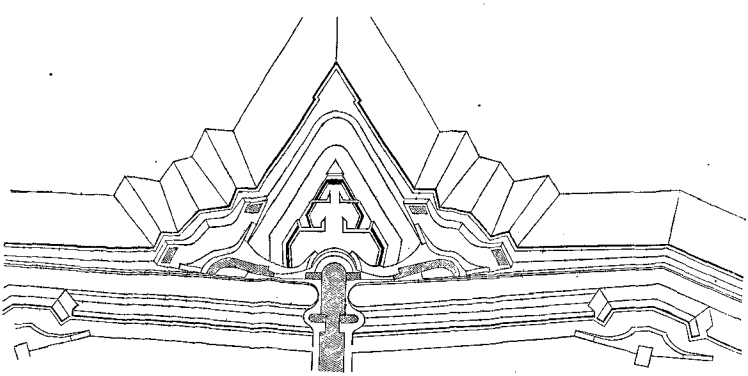
Previously to the invention of gunpowder, much depended upon individual strength, and the tide of battle was frequently hurled back by the prowess of one man, who thus became the champion of the host. Fortification also consisted principally of massive stone walls, with square or circular towers projecting from the face of the wall, as well as being carried considerably higher than the wall.

Nineveh, Babylon, Jerusalem, Carthage, and Rhodes may be mentioned as places of considerable importance, surrounded by massive high walls, and in many cases by double and triple walls. Ecbatana, the capital of the empire of the Medes, is said to have been surrounded by seven walls. The great wall of China was an attempt to guard an extensive frontier from the incursions of neighbouring nations; and, to come nearer home, the wall built by the Romans in Great Britain, in the beginning of the third century, may be mentioned. It was twelve feet high, eight feet thick, and seventy-four miles long, with battlements four feet high. This wall, though comparatively slight in its construction, was well guarded by numerous stations, castles, and watch-towers.

The invention of gunpowder did not work an instantaneous change in the system of fortification by exposed walls of masonry, as the shot used for some time were composed of rounded stones, and these, projected against massive walls of masonry, did not produce much effect. When iron shot were introduced, it was soon found necessary to abandon the high exposed walls, and to sink them under the surface of the ground, in order to protect them from distant fire. This involved the necessity of two walls, and hence the ditch surrounding modern fortresses, with the escarp and counter-scarp walls.

This alteration also necessitated alterations in outline, or trace, as well as in profile, and the result has been the bastion and the polygonal systems. The ostensible object of these systems is to ensure a flanking defence for the ditch, as being more effective than a direct defence.

Each of these systems has its advocates; and as the controversy has been carried on principally by French and German engineers, and as the bastion system is principally employed in France, and the polygonal system in Germany, these systems are now popularly known, the former as the *French* and the latter as the *German* system.



POLYGONAL SYSTEM OF FORTIFICATION.

Both systems have their defects even when tested by the old modes of attack, by smooth-bored cannon, and the now obsolete brown-bess; and these defects will be more numerous and more fatal when these systems shall be assailed by the improved cannon, and the greater range of the improved rifle.

The characteristic features by which the polygonal system differs from the bastion system is in the mode of obtaining flanking fire for the defence of the ditch. In the polygonal system the exterior side of the polygon about to be fortified, whether regular or irregular, remains nearly straight, and is not broken up in outline into parts, as exhibited in the bastion trace, to obtain retired flanks for the defence of the ditch. The flank defence for the ditch in the polygonal system is obtained by placing casemated caponiers in the ditch, either at the alternate angles of the polygon, in which position the caponier would defend two collateral sides of the polygon, or it is placed in the centre of a side of the polygon, and defends that one side only. These casemated caponiers are frequently made to serve as barracks.

The advocates of the bastion system assert that the polygonal system is defective in the following respects:—

1st. That it is more liable to be enfiladed than the bastion system, as it contains longer straight lines, or faces, and there would be a greater difficulty in placing the prolongation of long lines upon inaccessible objects than there would be in the case of shorter lines.

2nd. That the casemates are too numerous, expensive to construct, and difficult to ventilate.

3rd. That the splinters from the masonry would cause much damage to the besieged.

4th. That the escarp walls are not flanked from the body of the place, but that the defence of the ditch is obtained by caponiers, and by works more or less unconnected with the escarp walls.

5th. That the central caponiers and other flanking defences could frequently be destroyed by distant fire in the earlier operations of the siege, and, consequently, the defenders would be helpless against a close attack.

6th. That the detached carnot-wall would be destroyed by distant fire.

The defects of the bastion system are said to be the following:—

1st. An exposure to enfilade both of the faces and flanks of the bastions.

2nd. A want of cover for the artillery fire.

3rd. A loss of interior space, in consequence of such space being occupied by the curtains.

4th. The lines of defence being unnecessarily restricted in length.

5th. A deficiency of space for direct artillery fire.

6th. A want of good interior defence, and of the power to establish it.

7th. A liability in the flank defences to be destroyed by distant fire, so as to render them useless for the defence of the ditch when such defence becomes necessary.

8th. A want of defence for portions of the ditch when a tenaille is employed.

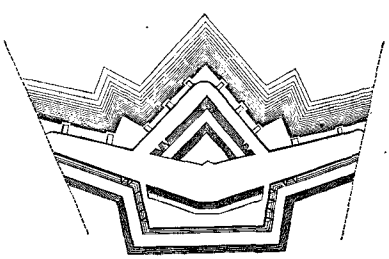
9th. The artillery fire from the ramparts is principally restricted to the command of small portions of ground in the neighbourhood of the fortress.

10th. This system presents a number of salient angles to the besiegers upon which they may direct their attacks in comparative impunity, as few guns point in the direction of the capitals. The system appears to be intended more for close defence than for the destruction of an enemy at a distance, and when he is about to commence his operations.

In both systems the guns of the besieged, if in barbette, are more exposed than the guns of the besiegers in their temporary batteries; and if the guns of the besieged are placed in embrasures, the horizontal range of each gun would be so limited that but few guns could be brought to bear upon any point where a battery was being constructed by the besiegers.

In the more recent constructions of both systems, *outworks* are generally abandoned, and *detached works* adopted, doubtless with a view to keep the assailants at a greater distance from the main body of the place than could be effected by the ordinary class of outworks.

These detached works may, however, be reduced in detail without receiving efficient support either from the body of the place, or from the nearest detached works.



BASTION SYSTEM OF FORTIFICATION.

As the existing systems of fortification are of very little security against the improved cannon, it might reasonably be supposed that no expensive constructions would be undertaken in this country until such improvements had been made as would be capable of resisting, as far as possible, the improved weapons. So far from this being the case, the very contrary course is manifested in the greater number of the works which are being constructed in various parts of the country. The high walls of masonry which shrank into the ground upon the invention of gunpowder are again making their appearance above the ground, as if in defiance of the improvements which make gunpowder much more destructive than it ever has been, and cause

its effects to be felt at much greater distances. We again hear of casemated keeps, and towers with masses of exposed masonry.

The most recent published description of the defensive works which are being constructed for the defence of our dockyards and arsenals is given in the 'Professional Papers of the Corps of Royal Engineers,' vol. ix. p. 129.

Guns placed in barbette upon the rampart of such works are in the best possible position for being knocked over; and the gunners whilst serving the guns would be nearly as much exposed to rifle fire as if no parapet existed. These keeps, and indeed the detached forts themselves, would form admirable shell traps. The detached fort with its keep would form objects that could not possibly be missed by the improved artillery from a distance of two or three miles; and a field battery could seldom be hit at that distance by the fire of the fort, so as to dismount guns placed in embrasures.

The guns in the fort and keep in barbette would by no means be placed upon equal terms with the guns in the temporary field batteries: and even the guns in the exposed casemates would soon be silenced, as the walls of stone or brickwork would soon crumble into ruins beneath the pounding of the improved artillery, even when placed at considerable distances. The casemates could not be repaired, or reconstructed, during the operations of the siege; and to repair the earthen rampart, which in its most perfect state neither protects guns nor gunners, would be a waste of time.

Those guns of the forts which could be brought to bear upon a distant assailant, being once silenced, the enemy can advance sufficiently near to shell the place which the forts have been constructed to defend; and it will be difficult to prove that they are more efficient for the defence of the arsenals and dockyards than temporary earthen batteries would have been.

There may be a sufficiency of flanking fire for the defence of the individual fort when an effort is made to capture it; but in the event of an invasion that is a process which no judicious enemy would think of wasting his time about. Having once destroyed the place for the protection of which the forts had been constructed, there would be no necessity to waste time in attacking the forts. They would rather be an advantage to the invader than otherwise, as the great force necessary to occupy these places would be prevented from taking the field; and the invader would find it more to his advantage to push on to London, the ultimate object of his ambition, than to waste time in the capture of forts which he could so easily mask and press on to the capital.

The invention of gunpowder abolished the use of defensive armour for the person; defensive armour must now be restored, not for the protection of a single individual, but for the protection, to a certain extent, of the mass. This has already been applied to ships of war, and must ultimately be applied to land defences, otherwise they will be of very little use, and not worthy of the name of fortifications or places of strength.

There can be no doubt but that the art of war will be very much changed by the modern improvements in gunnery, in the use of the improved rifle, and in the application of steam-power to naval warfare. If that change do not take place in its fundamental principles, it will in many of its essential details.

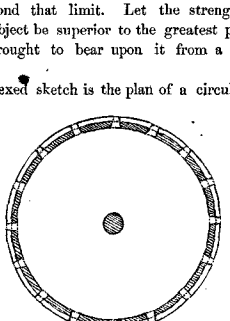
The art of fortification does not appear to have made improvements commensurate with those made in gunnery and small arms.

Modern improvements appear to have already turned the scale in favour of the defence; and it is probable that entrenched field positions will be much more frequently resorted to than formerly; and being more efficiently defended, will become more formidable, and more unassailable, unless attacked by something approaching to the operations of a regular siege; and if permanent fortification can be improved up to the point to which gunnery has been brought by recent inventions and improvements, the defence in war will be very much superior to the attack. When this will have been effected it will be very much in favour of the peaceably disposed, and peculiarly favourable to us in our insular position.

The following plan is an attempt to effect this very desirable object:—

There must be a limit to the destructive power of the most formidable gun that can be constructed; then let the strength of the tower, fort, or battery be something beyond that limit. Let the strength of the resisting object be superior to the greatest power that can be brought to bear upon it from a reasonable distance.

The annexed sketch is the plan of a circular tower,



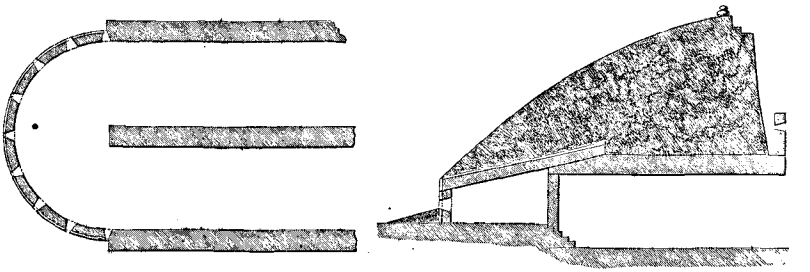
to be constructed on a rock, sandbank, or in any position where it would be desirable to fire in every direction. The tower may mount one gun, or two or three guns, but only one can be brought to bear upon the same object at the same time.

The peculiar and novel features of the proposed tower are, that the advantages or sweep of the barbette battery

is obtained without the exposure of the barbette. The sketch is about forty feet in diameter, with a pillar in the centre, to support the bomb-proof roof or covering, which is made of such a slope as most effectually to deflect the shot or shell which may strike it.

The embrasures or portholes would be so constructed that the fire from the gun would converge at any required distance from the tower. This would be regulated according to the peculiar circumstances of each case.

By a peculiar construction of carriage, hereafter to be described, the embrasures or openings will be reduced to the size of the muzzle of the gun, with the addition of the space necessary to lay the gun upon the object to be fired at; and those openings which are not in immediate use can be shut against rifle shot, or against the more formidable projectiles which may be sent against them.



The upper part of the tower and the roof to be formed of solid timber, covered with iron of such thickness as would be considered best adapted to its position, and to the destructive power that can be brought against it.

The coast battery, in the annexed sketch, would be in every respect similar to half of the tower already described, as respects the arrangement of the gun, carriage, and platform.

From the semicircular battery a casemate would be carried to the rear, for about 50 or 60 feet. This casemate would be sunk below the level of the battery, in order that a great thickness of earth may be placed over it. The casemate would give ventilation to the battery, and serve as barracks and stores.

In applying the same principle to permanent fortification on a more extended scale than that of an isolated tower or single coast battery, there does not appear to be any advantage in retaining the bastion trace; that of the tenaille will probably answer much better. In the accompanying sketch, an exterior side of 1,000 yards is taken, and a perpendicular of about 150 yards; but this may for the present be left an open question. The batteries would be precisely similar to the one already described with the casemate behind, and also the protecting mound of earth.

With 1,000 yards of exterior side, each face of the tenaille might mount ten guns, or rather have ten batteries, each mounting two or three guns, which could be used simultaneously when the works to be destroyed embraced an extended front, or kept in reserve in the event of a temporary or permanent accident to any one of the guns.

The battery at the salient would act equally upon each collateral face. The fire of the whole twenty guns in one face can be made to converge upon any one point, extending from the crest of the glacis to the most distant point of the range, over the whole of the ground in front of the face attacked; and to impede the progress of any works directed upon the capital, the whole of the guns mounted upon the two collateral faces can be brought to bear.

As the whole of the guns in the tenaille front give both a direct and a flanking fire, it will only be necessary to place four or five guns in the distance A B, and a like number in the distance A C, near the bottom of the ditch, with oblique embrasures, to sweep the ditches with overwhelming showers of grape. These guns could not be reached but from the crest of the glacis, and at that point no besieger could ever arrive with temporary works, under the concentrated fire of twenty guns playing upon him during the whole of his advance.

The superiority claimed for the attack over the defence rests principally on the power of enfilade possessed by the attack. By constructing enfilading batteries on the prolongation of the faces of all the works of the defence which can be brought to bear upon the attack, the guns in position upon these faces are dismounted in the earlier operations of the siege, otherwise these operations would be greatly retarded, if not altogether stopped.

In the proposed system the guns and gunners would be so protected, both from direct and enfilade fire, that at no period of the siege could the guns be dismounted, or rendered ineffective. The whole of the guns upon

the face attacked would, on the proposed system, command the entire sweep of the works of the attack; and they also could all be concentrated on any one point, from the crest of the glacis to the utmost extent of the range. Under these circumstances it is difficult to suppose that an attack can be successfully carried on, at all events above ground.

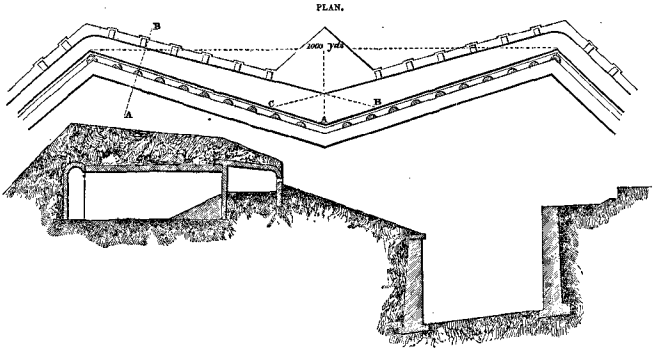
These bomb-proof batteries would be kept so far back from the top of the escarp wall, that their stability would not be affected by the breaching of the upper part of the wall from a distance; and the intermediate space would be covered with every imaginable obstruction that could be placed upon it, which would not interfere with the range of the guns.

The superiority of the proposed system of fortification over existing systems is not only claimed on the score by iron mantlets of sufficient thickness to resist rifle shot, wall-pieces may be introduced to meet this contingency, which may be placed temporarily in any convenient position, or fired through the embrasures of the batteries, and of such power as to destroy the heaviest mantlets that could possibly be pushed forward from behind. This arrangement would save the ammunition of the guns, and be equally efficient in preventing the advance of the sap.

The proposed system ought not to be indifferent to a Government who are expending millions upon fortifications very much of the old type, and by no means adapted to cope with the recent improvements in guns and projectiles.

The travelling platform, by which one gun can be brought to several embrasures, and to any required

PLAN.



SECTION ON LINE A B. Scale 40 feet to 1 inch.

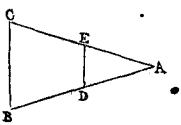
of efficiency, but also on the score of economy. On the present system, guns firing from embrasures have but a very limited lateral range, and a still more limited concentration; consequently a much greater number will be required to command the whole extent of the works of the attack. It is not too much to assert that two-thirds of the number of guns and gunners, upon the proposed system, could be saved, and that the remaining third will give as great an effective fire as by the existing system. As the improved guns are very expensive, this would be an important saving, and would meet the additional expense of effectually securing the guns and gunners by an impenetrable shield; also, that by effectually securing the guns against attacks by sea, and against any temporary works that could be thrown up on land, each gun would be worth ten exposed as at present; and thus an additional saving to a considerable extent would be effected in guns and men.

Ample scope, from a good elevation on the ramparts, would be given for rifle fire; and as the heads of advancing saps will, no doubt, in future sieges be protected

angle of obliquity at each embrasure, would be constructed as follows:—Two iron circular rails would be placed round the inside of the tower or battery, the outer rail about six inches from the inside of the wall, and the second rail about two feet inside the outer rail. Upon these rails a low truck or bed would be placed, mounted upon four wheels—two wheels upon the outer rail and two upon the inner rail. The wheels would be flanged so as to keep the truck upon the rails. Above the centre of the truck a pin would project, upon which the travelling platform would move as upon a pivot. This moveable pivot could be arranged in a variety of ways. The rear end of the platform would be supported upon two wheels, which would not move on a rail, but on the paved floor of the fort or battery.

The gun carriage, which would be required to elevate or depress the gun, when the aperture to be fired through is very little more than the size of the muzzle of the gun, must be constructed so that when the gun is run fully up, it may be elevated or depressed whilst the muzzle remains stationary.

The principle by which this is effected is as follows:—Let A represent the muzzle of the gun; A B, the axis of the gun when placed at the greatest elevation at which it may require to be placed in its particular position; A C, the greatest depression to which it would be necessary to bring it. The vertical range of the gun would therefore be from the line A B to the line A C.



This principle may be carried out in a variety of ways, by screws or by levers. The line A B being divided into two equal parts, the motion given to B C must be double the motion given to D E, which movements being combined and simultaneous, will retain the point A, or muzzle of the gun, stationary in the aperture through which it is to be fired.

The above is a mere outline of the proposed system, without any attempt at detail.

The numerous experiments which have recently been carried out in this and other countries clearly prove that the most massive granite walls cannot resist the improved ordnance. The conclusion which has been arrived at, from extensive experiments made in Italy, in the demolition of a fortress, is that "It is evident, in the first place, that fortification works whose walls are visible have henceforth no value whatever at the greatest distance." And one of the ablest of our military engineers, after referring to the late experiments of guns against fortification, concludes with the following remark—"The time has arrived when in defensive works *new forms and new materials* must be adopted."

GRANITE AND IRON FORTS.

[PLATE B.]

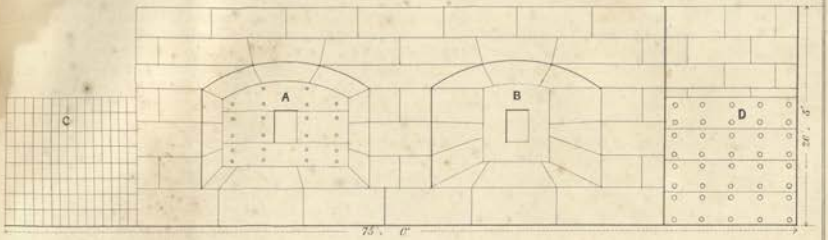
NOTWITHSTANDING the great attention which the above subject has received from all classes of Engineers, the discussions it has elicited in Parliament and the Press, and the expenditure of vast sums of money on experiments, it is still far from being satisfactorily solved. Indeed, after several years of vacillation, in addition to this great expenditure of money and talent, the first practical step has not yet been taken, in our own country, towards its solution. Had this been an open question—that is, a question practically open to the public, like any railway, hydraulic, or other engineering question—there can be little doubt but that it would have been at least in a more advanced state than it is at present. But, however much it may be studied and considered by great contractors and their professional assistants, it can only be practically dealt with by the Engineers in the War Department. Now, unfortunately, it is not necessary that a Royal Engineer should be a talented, or even an energetic or persevering man, as the Civil Engineer must be, in order to rise in his profession. On the contrary, the quiet, easy-going officer, who thoroughly understands the routine of his department, and peremptorily refuses to step out of it, has by far the best chance of succeeding in the official race for promotion and advancement. Hence, it will not be a matter of surprise that there is little progress to record in the matter of Iron Forts, between the trials of the Thorneycroft bars in 1860–61, and that of the Granite Casemate tried at Shoeburyness in November last. The interim experiments, which may be disposed of in a few words, were uninteresting in themselves, and their result nil. They consisted chiefly of bars of iron, about 18 inches wide and of various thicknesses, laid transversely, and built up in the form of shields for embrasure.

The trial of the Granite Casemate, represented in Fig. 1, commenced on the 16th November last, and was conducted by the Ordnance Select Committee, assisted by Col. Jervois, R.E., and Major Inglis, R.E., Superintendent of Works at Shoeburyness. This structure, with its area of about 1,500 feet, presented five distinct features or combinations to the guns. First, the granite work; second, the compound shield A (diagram No. 1); third, the solid plate shield B; fourth, the right or east wing facing, C; fifth, the left wing facing, D. The granite work was composed chiefly of masses of stone of from 8 to 10 tons each. Some of the courses were 3 feet in thickness, the stones being 8 or 10 feet in length, and from 4 to 5 feet in width. The entire thickness of the granite wall, including a 2-feet lining of brick work, was 14 feet.

The shield A, for the large embrasure, 12 feet × 8, was made at the Regent's Canal Ironworks. It had a front plate of 4 inches thick, and a backing of thin iron plates 8 inches deep, their outer edges supporting the front plate, and their inner bearing on a second armour plate of 2 inches in thickness. This, again, rested upon a cushion of teak timber 6½ inches thick, the whole bearing on a skin of inch-iron, and bound together by 22 bolts of 3 inches diameter, and 16

EXPERIMENTAL CASEMATE, SHOEBURYNESS 1865.

FIG 1.



DETAILS OF THE CHALMERS SHIELD A.

FIG 2.
Front Elevation

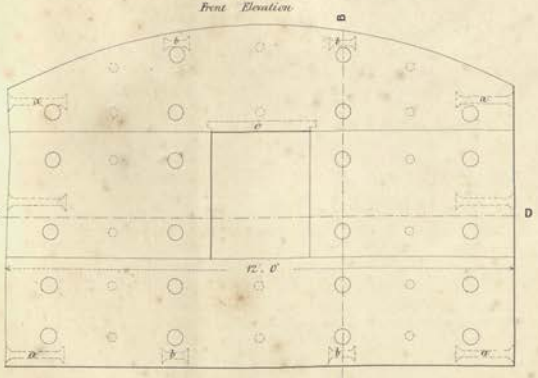


FIG 3.
Section on A.B.

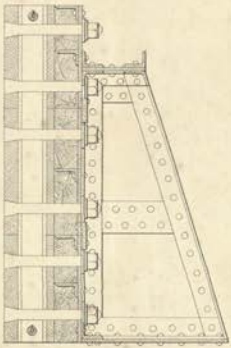


FIG 4.
Sectional Plan on C.D.

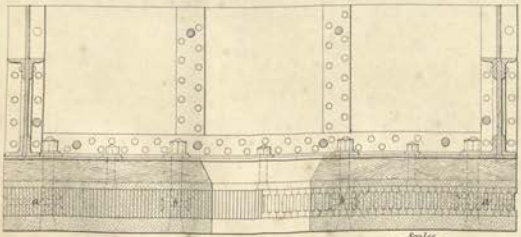
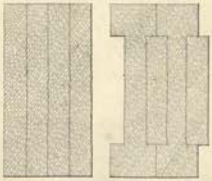


FIG 5.
Section of Backing bars.



Scales
Scale for Fig 1.
Scale for Figs 2, 3 & 4
Scale for Fig 5.

W. Hunter dir. London: Lockwood & Co 7, Stationers Hall Court.

bolts of 2 inches, all having shallow square threads. The skin was attached to two struts by double angle-bars 6″ by 4½″ by ¾″, and strengthened by six similar bars running at right angles to the struts. A strong H girder, 18 inches deep, strengthened the shield across the top of the embrasure. The struts to which the shield is attached rested upon a bottom plate of inch-iron, 8½ feet wide, and through this plate the entire mass was secured to the stone work by 10 bolts of 2½ inches diameter. The backing bars, where cut to admit the passage of the through bolts, were bound together in bodies by the rivets *a*, *b* (Front Elevation), and the short bars over the porthole were kept in their places by the lintel *c*. This shield owed its origin to the successful trial of the Chalmers target in April 1863, and the recommendation of Lord Palmerston, who introduced the inventor to the Secretary of State for War. As originally proposed, the principle was the same as the Chalmers target; but at the suggestion of the late Iron Plate Committee, and the Engineers of the War Department, it was altered to the form represented in the accompanying diagram. For the compound backing, or alternate layers of timber and iron of the original design, the present backing of layers, all of thin iron, was substituted, on the ground that it was not advisable to introduce such a perishable material as timber in a permanent work. Half of the shield, therefore, has a backing of plain bars 8″ by 1″, and the other half has bars which match or bind into each other (see Fig. 5). The latter were suggested by Mr. Chalmers, and their adoption for the entire shield would only have added about £10 to its cost. These alterations, while they still leave a cushion of timber in the very heart of the structure, add greatly to the weight and cost of the shield, without improving its powers of resistance. This shield has cost over £1,000 (independent of the consideration paid to Mr. Chalmers for the invention and superintending its construction, £600); but a shield of the same size, on the plan originally submitted (which has been shown to offer greater resistance to shot), would have cost only about half this amount.

The western shield B, designed by Major Inglis, R.E., Superintendent of Works, was manufactured by Messrs. John Brown & Co., of Sheffield. It was simply a solid plate of 13½ inches in thickness, with a porthole 3 feet × 2′ 4″. It had no fastenings or backing. At top and bottom it was let into the stonework about 6 inches; and in order to keep it up to its work, it was further supported by bars of railway iron embedded in the stonework, which was fluted to receive them. The right flank of the casemate was protected by the cramped iron-facing, C, generally termed "the puzzle," because the pieces of iron bind into each other in the manner of certain puzzles made of wood for the amusement of children; and the left flank, D, was protected by 4½-inch armour plates, backed with timber and concrete. The entire cost of this experimental structure, including cost of trial, was about £8,000. The battery to test the structure was placed at 200 yards' distance, and consisted of the following guns:—

7-inch shunt,	throwing a steel shot	115 lbs.	with	18 lbs.	ch.
8	"	"	"	150 lbs.	" 22 lbs. "
9¼	"	"	"	220 lbs.	" 30 lbs. "
10	"	"	"	280 lbs.	" 36 lbs. "

The latter charges were increased to 41 lbs. when firing at the compound or Chalmers shield A. Against the stonework cast-iron shot only were used.

It is not necessary here to give a detailed account of the firing. The following graphic account, from an able article on "The Spithead Forts," in the *Saturday Review*, gives a correct summary of the result of the experiments:—

"The experiments were directed to two distinct objects—first, to test the comparative resisting power of the two shields; and secondly, to ascertain how long the huge mass of granite would be able to stand the fire of the formidable battery. In order to approximate more closely to the conditions of a probable attack, the charges of the guns were reduced, so as to give the same striking velocity as if they had been fired at 1,000 yards—a precaution somewhat lenient to the fort, though, as the result proved, not sufficiently so to save it from destruction. The practice on the shields exactly accorded with previous experience. The solid plate was seriously damaged, and a few more shots would have knocked it fairly away.* The Chalmers target stood well, as it has always done before; it kept out all the shots, and suffered no great injury beyond the snapping of several of the bolts. The battery was then turned upon the masonry, and though only cast-iron shot were used, the first blow fairly split a huge mass of granite far in the rear of the point of impact. Still the shot did not get through, though the ultimate fate of the structure might easily be foreseen. Two rounds from the four-gun battery were then completed. Of the eight shots, one missed altogether; but the other seven struck the granite walls. Upon examination, it was found that a great part of the casemate was a heap of ruins, and that one of the shots had forced a clear passage into the interior of the work. The conclusion is that seven well-directed shots, from a range of 1,000 yards, will suffice to annihilate the projected Spithead Forts, and that all the labour and money bestowed upon the works will have been thrown away, unless some better material than granite can be found for their construction. . . . . It seems pretty clear that the granite gave way, less from the destruction of its face than from the want of elasticity which made the whole mass crack and fall to pieces under the blows to which it was subjected. An iron facing,† unless backed by wood and converted into armour strong enough to need no further backing, would do very little to break the shock upon the inner wall of stone, and there is scarcely room to doubt that the first experiment upon it has finally settled the fate of granite as a material for a first-class fort. If it were certain that this conclusion would be accepted without reserve and without delay, there would be nothing to cause alarm in the failure of this first design for our harbour fortresses, but it is sometimes easier to demolish the stoutest materials than to batter down a preconceived idea. Perhaps in this particular instance the failure of the proposed design has been too conspicuous and too startling to be altogether without effect. It is scarcely conceivable now that the defences of Portsmouth will be actually built of a material so worthless as granite has proved to be; but it is quite possible that the cause of Iron *v.* Granite for the defence of forts may be as tedious as the cause of Iron *v.* Wood was in the construction of ships. In all these matters the rule

* The thick-plate shield, which was disposed of at the fourth round, was struck by a total of 765 lbs. of metal, propelled by 106 lbs. of powder; whilst the built-up, or Chalmers shield, resisted 2,445 lbs. of metal, and 311 lbs. of powder.—*Army and Navy Gazette.*

† Such as the right and left wings C and D of Fig. 1.

seems to be to cling to an old prejudice until it is fairly battered to pieces, and we only hope that the moral resistance of the granite theory may prove as feeble as the physical resistance of the material itself."

Granite having been effectually disposed of as a material for forts, the superstructure of the works at Spithead will probably be chiefly of iron; in which case, reason, science, and all past experiments alike suggest that a large portion of the material should be composed of plates having their edges opposed to the attacking projectile. An arrangement similar to that of the Chalmers Shield, or perhaps a compromise between it and the "Naval Armour," by the same inventor, referred to in *Record of Modern Engineering*, 1863, could doubtless be extended to the entire walls of these forts, with advantage as regards resistance to shot and economy of space, if not of cost, as compared with granite.

THE RATIONALE OF RAILWAY ROLLING STOCK.

[ILLUSTRATED BY PLATE A.]

THIS name was given by Captain Huish in order to distinguish the moveable stock of railways from fixed plant. It was not a happy selection, inasmuch as the stock in question when in transit did nearly as much sliding as rolling, and the term "moving stock" would have satisfied both conditions—a conclusion that our French neighbours had arrived at by their logical process. From the time that the first wagons rolled on the "way leaves" of the North, men conversant in transit have been alive to the desirability of rolling movement for the diminution of haulage labour, but it is a conclusion still only made practical in a few experimental cases.

One important distinction between traction on common roads and that on tramways and railways we are too apt to overlook, viz., self-guidance. In the old coaching system of fast driving, with the contingency of rebellious horses, and the passing by other vehicles, driving was an art involving many high qualities—perfect self-possession, complete manipulation of whip and reins, clear vision, readiness in emergency, and hardihood against the weather. The "four-in-hand club" was not wholly an absurdity, for it was a test of manhood of a certain class. There was no possibility of preventing a pair of wilful leaders from upsetting the coach, if so minded, and only the thong was available to restrain them. With the advent of the rising edges on the tram-plates, self-guidance of the wheels ensued, and the chief labour of the driver ceased. The tram was far from perfect, for it was subject to much lateral friction, and a surface holding dirt, but when the edge rail supplanted it the principle of guidance was perfect in its theory, but far from it in practice, owing to imperfect structure. And with the abandonment of horses and the substitution of the steam-engine, the art of driving resolved itself into a knowledge of the gradients and curves on the line, and when to quicken or lower the fire, or turn steam on or off. The engine was not a wilful, but a passive slave, and the necessity for manhood in the driver, resolved itself into presence of mind in case of impending collision, before or behind, with a rapid succession of trains, and power of resisting bad weather, and with the advantage of hugging the boiler for warmth in case of extreme cold.

The principle of guidance was as complete 36 years back, when the Liverpool and Manchester was opened, as it is now. A flange round each wheel, an inch in depth, rounded at its inner and outer angles, and loaded with a weight of half a ton upwards, offered an apparently insurmountable obstacle to getting off the rails. To make this "apparently" still more secure, the wheels were made conical on their peripheries, diminishing in diameter outwards, as their width increased. The effect of this was to keep them central between the two rails, just as a river seeks its deepest channel, and thus to keep the flanges from rubbing against the rails. This principle was quite sound as regarded a single pair of wheels kept steadily rolling parallel to the rails, and with the axle at a right angle, but many adverse circumstances arose so soon as two pairs of wheels were applied to construct a four-wheel vehicle.

To begin at the beginning; the so-called wheels were not wheels at all, in the sense of the word wheel as used on roads, but only garden-rollers, with the centres reduced to an axle diameter, and the outside peripheries coned. The two wheels being keyed, fast on one shaft, to avoid the trouble and expense of wheels and axles proper, could only roll along a straight line in virtue of their diameters being equal, or along a curved line in virtue of their diameters being unequal. But this compensating process ceased to act so soon as two axles were fixed in one frame without power of radial movement. From that time the movement ceased to be rolling, and became a compound of rolling and sledging, and it is a known fact that if a vehicle so constructed were supplied with wheels of one-fourth greater diameter on one side than the other, such a vehicle, if drawn over a plane sur-

ROLLING STOCK.

FIG. 1.

FIG. 2.

AXLE BOX

FIG. 13.

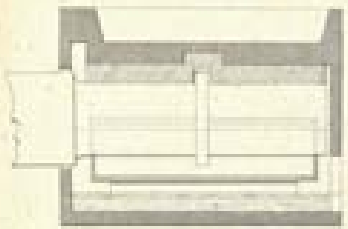
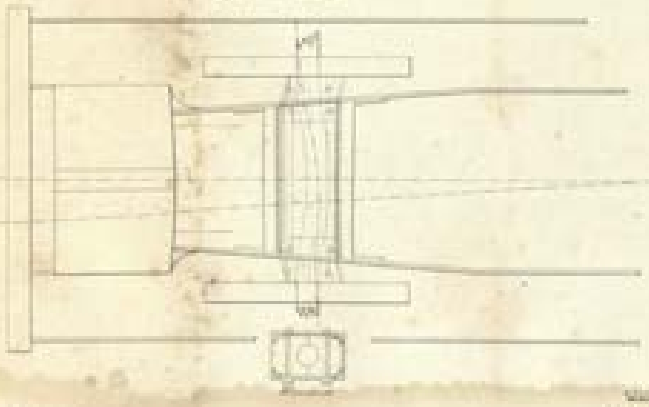


FIG. 14.



PLAN FIG. 15.

FIG. 3.

FIG. 5.

PLAN FIG. 4.

PLAN FIG. 6.

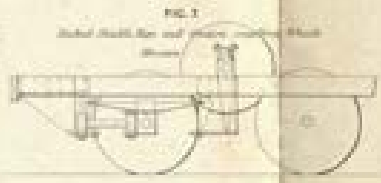


FIG. 7.

FIG. 8.

PLAN FIG. 8.

FIG. 12.

PLAN FIG. 10.

PLAN FIG. 10.

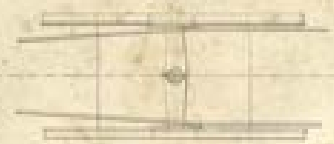
FIG. 9.

PLAN FIG. 11.

FIG. 18.

PLAN FIG. 14.

FIG. 17.



PLAN FIG. 17.

FIG. 19.

face without rails to guide it, would only advance in a straight line if the axles were perfectly parallel, and only on a specific curved line if the axles were out of parallel. The only mode in which the so-called wheels could be made to roll would be by using them with two-wheeled carriages, that is, with a horizontal joint between every pair of wheels, and this would involve other considerations of disadvantage in trains. In short, from the time the Liverpool and Manchester opened until now, the practice on railways has been to force parallelograms round curves with more or less resistance in proportion as the vehicles have been longer or shorter, and the curves of small or large radius, the movement of the so-called wheels on the rails being alternate sliding and rolling. The polish which may be observed on the surfaces of both wheels and rails where their contact takes place, is proof of this. The result of this vicious practice was of course straining the axles by torsion and grinding both tires and rails by the sledging movement, involving great extra power in haulage, and causing a waste of fuel. For this reason tires had to be made thicker, and axles stronger, till the rails got the worst of it, and had to be strengthened and improved in turn.

An illustration of this evil may be taken from agricultural practice. There is an implement called a clod-crusher: it originally consisted of a cylinder of cast-iron, some 18 inches in diameter, and 4 to 5 feet in length, set round with coarse teeth, which crushed the clods as it was drawn over a ploughed surface. But the labour to the horses was enormous. It was lessened by dividing the cylinder at the mid-length, so as to make two broad wheels revolving independently on an axle. These again were divided into four, with still greater advantage, and finally, the whole cylinder was divided into a series of narrow discs, each containing a row of spikes, and thus the minimum of resistance was arrived at with the maximum of effect.

Railway wheels are in their present condition analogous to the condition of the clod-crusher at the outset, but they have a certain compensation in being enabled to slide upon hard iron surfaces.

It was probably the perception of these difficulties that caused the first vehicles of the Liverpool and Manchester to be kept short. And in an overweening confidence in the smoothness of the new road they were constructed, first, without springs, secondly, with very short springs, which on the general railways have gone on lengthening from their original 18 inches to 6 and 7 feet.

So also in practice a new element became apparent. The "bumpers," or blocks, at the wagon ends, which answered well enough for the transport of minerals at slow speed, would not do at all for passengers, and "buffers," or stuffed cushions, were first applied, and then sliding rods connected with steel springs. As speed increased lateral oscillation increased also, and then Henry Booth produced the right and left screw coupling, which drew the whole train up into a half solid, half elastic column, thus steadying it, but at the cost of greatly increased friction between the wheels and rails and end wear of the axle brasses, the wheels constantly trying to run along the path of least friction, and as constantly resisted by the compression of the couplings.

It is instructive to watch the proceedings of the driver of a goods or mineral train of great length when just getting it into motion. He first backs every wagon one upon another till the whole train is comparatively solid. He then easily starts the first wagon to the length of the loose coupling chain. That being in motion, the momentum gives additional force to start the second, and so on till the whole is moving, subject to the difficulty of the sudden snatches breaking the coupling if not sufficiently provided with traction springs. But for this practice it would be utterly impossible for the driver to move the train at all.

And if the train be watched from an over bridge, it will be seen that each wagon has its own peculiar movement, causing the whole train to assume an irregular wriggle, analogous to that of a snake on uneven ground. The meaning of this is, that every wheel in the train is striving to find out the path of least friction along the numerous irregularities of the rails, the practical curves of very small radius, not intentionably set out; and it will be found that when the train enters a very sharp curve of regular form, a steady movement ensues. This is induced by the flanges of the wheels all bearing steadily against the rails with greatly increased friction; and, as a general rule, trains run steadier on curves.

It will thus be seen that passenger trains run slowly in virtue of constituting to a certain extent one long carriage subject to enormous friction, a very long parallelogram, which may answer tolerably well on straight lines, but which is very costly and disadvantageous on curves or lines out of order, necessitating much greater strength in the vehicles and much heavier wheels, all of which act with compound mischievous effect in case of collision.

It will therefore be understood that if a carriage could have its base sufficiently extended in its own length to constitute steadiness there would be no need for close coupling the train, and this would at once get rid of much surplus haulage. A frame of 42 or more feet in length, with a wheel base of 30 feet, would suffice for this. But inasmuch as the cause of wheels running off the rails is that they are in a position not parallel to the rail, but at an angle with it, it is necessary to provide for them free movement, so as to keep them always parallel with the rails. Another reason for getting off, is the inefficiency of the bearing springs in not permitting the wheels to rise and fall freely with

the inequalities of the rail surface, so that the flange is held above the level, like a dog with his fore foot lifted.

"The longer the carriage the steadier it will be," is an axiom scarcely worth proving; but the history of the Great Western furnishes the proof ready-made. The earliest carriages thereon for the seven-feet gauge were of the same length as those of the narrow gauge,—about 8ft. 6in. from axle to axle—four-wheeled. When tried, they jumped up and down like a pitching vessel at sea, shuffling the passengers off their seats. It was evidently necessary to lengthen them, and this was done by applying another pair of wheels to carry the load, and thus longitudinal steadiness ensued.

In proportion to the length of a carriage the width may be advantageously increased. As a rule the width of the carriage may be double the width of the gauge. The width of the rails of the narrow gauge is about five feet, centres, and therefore the bodies might be ten feet, if the side and middle spaces of double lines of rails permitted it. A carriage 42ft. by 10ft. gives 420 feet floor area, with an open space of buffers of 40 feet area. Comparing this with two ordinary carriages of 20ft. by 8ft., we find 320ft. of available area with 64 feet area of open buffer space, giving to the long carriage 100 feet extra passenger space, with a saving of 24 feet in buffer space. This is equal to about 25 per cent. saving in the length of platforms; a very important consideration; and it is also important as to hauling, whether by pressure of the flanges in curves or by the action of a side wind or a front wind, as the impinging area consists very largely of the open spaces in the trains, which would be diminished one-half by the use of the long carriage.

There is yet another advantage in the wide long carriages; they afford the facility for a central passage for the guard throughout the whole train to serve as a policeman. They afford facility for passengers to find out their friends; they afford facility for closets and for refreshment rooms, economising time on a long journey; they afford also facilities for helping passengers suddenly taken ill, and facilities also for warming and ventilation, and as a greater inducement to shareholders they economise the cost per passenger. It is not the mere difference in the first cost of first and third-class carriages that constitutes the calculation, but the area of space occupied by each. Other things being equal, the cost of hauling a carriage is so much per ton, and the larger the space occupied the greater is the dead weight per passenger. Third-class occupy only half the space of first-class, and, saying nothing of cloth, lace, and trimmings, the dead weight of the vehicle will be only half in proportion.

There is yet another consideration. With large carriages the number of couplings is reduced in a proportion of more than one-half, and, with loose couplings, the time occupied is lessened by one-half, and thus the risk of accidents is very materially reduced. And in case of collision, the risk of the train being broken up by the several carriages riding on each other's backs is much lessened.

The same principles hold good with regard to the construction of wagons. A short four-wheel wagon constantly pitches and oscillates and disturbs its load, and more especially with a high load. In the item of coals the breakage thus ensuing is considerable. We find that in sea-borne coals economy of transit demands much larger vessels than was formerly the rule, and the same thing holds good with wagons on rails. But the development of this principle has been prevented by the sharp curves which have prevented long wagons from getting to the pit's mouth, and this is a question of improved structure.

The general principles that should govern the structure of railway vehicles are as follows, supposing the railways adapted to them as regards space:—

1. The width of the body or frame should be double that of the gauge of rails.

2. The length of each vehicle should be four times the width of the body, or eight times the width of the gauge.

3. The springs for carrying the load should be thoroughly elastic, with a rise and fall through ample space, to elude concussion, and prevent the wheel flanges from rising above the rails at inequalities of surface.

4. It is desirable to multiply the wheels in each vehicle, each wheel carrying the most economical load, having regard to wear and tear, as thus damage is lessened to the rails and way, and the risk of breaking springs is diminished by the simultaneous action and the absence of pitching movement.

5. The mechanism of the wheels should be so arranged that under all circumstances, whether on straight lines or curves, the wheels should always be all parallel to the rails, and the axles at a right angle with them.

6. The wheels should not be keyed fast on the axles, but should have independent revolution, either at the axle or at the tire, so as to prevent all sliding friction between tire and rail on curves.

7. Each vehicle of the train being sufficiently long to run steadily by itself, should be coupled to the adjoining vehicles by a loose link, and not by a tight coupling.

8. The traction rods should run through the vehicle as a continuous bar, with longitudinal spring action, or an equivalent framing should be used, and with free radial movement in the headstock.

9. In all passenger trains there should be sufficient central space for the guard to pass from one carriage to another throughout the whole length of the train, and this without interfering with the privacy of first-class passengers.

10. The retarding or brake power should be applied

to every carriage, and if possible to every wheel in the train. It should be so arranged as to be applied at pleasure by either guard or driver, and to be instantaneously self-acting in case of the separation of the continuity of the train by accident.

In the question of haulage, the first consideration is whether the engine is intended for high speed, or for heavy loads and steep gradients. If for high speed and light loads, a single pair of driving wheels may suffice, but the fore and aft wheels should be so extended into a long wheel base, with such perfect action of the springs as to ensure steadiness and "bite" on the rails. The longer the wheel base the steadier the engine will be. But provision must be made for lateral radiation, to keep the wheels parallel to the rails.

If a heavier load be needed, the driving wheels must be duplicated by coupling to a second pair either by side rods or by friction coupling wheels. The usual disadvantages of coupled wheels arise from impedimental friction, i.e. friction not useful for adhesion. If four driving wheels—two of which are driven by the cylinders—be connected by side rods, the accurate action must depend on the wheels being all of exactly equal diameters, and on the side rods being accurately keyed to the crank pins at equal length. But this is only adapted to straight lines. If upon curves, either two or all four of the wheels must slide or sledge, and the tires will then wear unequally, and become sledges on the straight; thus requiring to be turned up to renew the equality of diameters. And if one or more of the tires be softer or harder than the others, this mischievous wear will be exaggerated.

There are two methods of moderating this difficulty. The first is, to arrange the tires so that they may slip round on the wheels upon smooth and extended surfaces between wheel and tire, and not between tire and rail. The second is, to substitute friction coupling wheels for the side rods, so that whatever be the diameter of the wheels, they will act equally well without strain upon the axles.

For an engine required to draw a heavy load, it is essential that the whole weight of the engine should be available to the adhesive power of the driving wheels on the rails; for the adhesion depends, other things being equal, on the load. If the load be insufficient in proportion to the steam power employed, the wheels will slip on the rails, and therefore the load should be at least four times that of the steam power when plane surfaces of tires and rails are used, increasing in proportion to the slipperiness of the rails. If the wheel tires are perfectly rigid, a much more perfect rail will be required than where spring tires are used, i.e. elasticity applied between wheel and tire. When a pair of coupled driving wheels—that is, two wheels coupled rigidly on the same shaft—are used to pass round a curve, the shaft must be exposed to more or less torsion, and the wheels to strain, and in this condition they jump from point to point on irregular rails, and slip with more or less mischief as the shaft regains its normal position by reaction of the torsion. When two pairs of wheels are coupled together by side rods the mischief is increased, and, *a fortiori*, where three or four pairs are coupled together by side rods.

When spring tires are used these evils are much alleviated. First, the tire slightly flattens on the rails. Secondly, it can rock sideways to equalise the tread on uneven rails. Thirdly, blows cannot take place. Fourthly, the wheel can, on emergency, slip round within the tire, to prevent the tire from slipping on the rails on curves. Lastly, there is no need of any great shrinking tension in applying the tires on the wheels, and there are no holes through the tire, so that there is no chance of the tire bursting when in action. Experience on various lines has proved that tires so applied quadruple their durability, and positive experiments, long repeated, show that they have 20 per cent. more adhesion in ascending inclines as compared with rigid tires.

There is another advantage. A heavier load may be borne on spring tires without damaging the tire or rail. Seven tons on a wheel may be as easily borne on a spring tire as five on a rigid one.

In the common construction of engines, it is essential to make them short on their wheel bases, to enable them to pass round curves. This has usually limited the driving wheels to three pairs coupled. But it is evident that the greater the number of wheels with equal loads the better will be the adhesion; and it is now practicable, by making the fore and aft wheels radiate to curves, to keep the wheels parallel with the rails under all circumstances. And by means of friction-wheel couplings between the crank drivers and the other wheels, every wheel in the engine, whether eight, or ten, or more, may be made adhesive, whether on the straight line or on the curve, and, with a proportionate increase of cylinder diameter, to draw any large load without loss of haulage by impedimental friction, and without damage to tires or rails. Of course, the smaller the diameter of the driving wheel in proportion to the length of stroke of the piston, the larger will be the load that may be drawn, but at a limited speed. But high-speed trains as a rule require smaller loads.

With regard to the mode of coupling by friction wheels, their advantage has been demonstrated by actual experiment which corresponds to their true theory. In coupling wheels by means of cranks and rods, it is essential that the work should be perfectly accurate as to the lengths of the cranks and the lengths of the rods, and also that the diameters of the wheels should be exactly equal. If there be any variation in the lengths or in the diameter, the result must be sledging on the rails, causing grinding, wear, and waste,

and torsion of the axles tending to break them, with great waste of power, involving friction, and not available for duty or haulage. And although the engine when first constructed may be perfectly accurate, the process of wear very soon destroys the accuracy. One tire may be softer than another, and so lessen its diameter in sliding along the rails, and in keying up the coupling rods as the bearings wear, the work may be done inaccurately. But even supposing the engine to be quite accurate in all its parts, it is only so as regards a straight line with rails like a pair of lathe-beds. On curves it is a mere sledge in which one wheel counteracts the movement of the other by friction, which is not useful, but impedimental. It is true that the coned diameters of the wheels may, by using sufficient play between the flanges, allow a certain compensation on curves, but this is only on the supposition that the curves are quite regular—a supposition not borne out in practice, as may be seen by the serpentine line, marking the surface of the rails and denoting the path of the wheels.

Theoretically, every axle should be rectangular to the rail on straight lines, and on curved lines it should point accurately to the centre of the curve, varying its position with the variation of the line. But where wheels are coupled by side rods, either four or six, the axles cannot vary with the curves, nor can the wheels run independently, to compensate for the difference in length of the tire rails. The only remedy in such case is to allow the tire to slip on the wheel instead of on the rail, and the slip in such case, with spring tires, is found to be no more than is needed to prevent torsion of the axles without affecting the usual adhesion on the rails essential to the haulage of the train. However loose the tire may be, it is evident that the load of the wheel will press on the lower half diameter.

In sheet A, Diagrams Nos. 1 and 2, are shown spring tires for engines and carriages in cross sections. The spring is a hoop of tempered steel tapered edgewise, and overlying a hollow in the tire. Thus the wheel bears on the apex of the springs, and the tire can rock laterally to fit the rails, and can slightly flatten on the rail to induce better adhesion, while the slip round compensates for unequal length of the rails. In the carriage-wheels, there will not be weight enough to flatten the tires, even though made considerably thinner than they are required to be when rigid, for there is scarcely any strain upon them. The wheels are kept in position in the tires by the back ring which springs into a groove, and thus renders them perfectly safe, indeed much safer than ordinary wheels, inasmuch as there is no tension tending to burst the tire.

A simpler and cheaper structure of spring tires may be applied for common wagons. Radial movement of the axles may be given in two or three modes. Diagrams Nos. 3 and 4, sheet A, are outline elevation and plan of the Great Northern engine, as regards wheels and axles. There are four coupled driving wheels as usual near the cylinders in front, forming a wheel base of 7ft. 6in.; 12 feet behind them, making a total wheel base of 19ft. 6in., are placed a pair of trailing wheels with radial axle boxes, moving on a curved line to right or left beneath the spring shoes which are fitted with brass bearings. The water is carried in a tank over the radial wheels, amounting to 1,000 gallons, and whether the tank is empty or full, the only difference in weight on the driving wheels is three hundredweight. These engines will run round a radius of four-and-a-half chains, or 300 feet, and run with perfect steadiness on the straight line at a speed over 50 miles per hour, either end foremost.

The length of wheel base being 19ft. 6in. on six wheels, it yet becomes practicable to increase that base to 31ft. 6in. by applying another pair of radial wheels to the other end while retaining the facility of passing round the same curves. In this mode the fuel may be carried behind the fire-box, and two thousand gallons of water in a tank in front of the smoke-box, making an express engine available for any distance or speed. The Diagrams 9 and 10, sheet A, are an elevation and section, showing a tank bolted to the smoke-box, forming as it were a continuation of it, a tube being carried through the whole length to warm the water and clean the fire tubes of the boiler, the smoke-door being fixed at the end of the tank.

It will be seen that a certain amount of friction is involved in the movement of the spring bearing on the top of the radial axle-box, and although the tendency of the curvature of the axle-boxes is to keep the wheels central, still the movement must be effected by the pressure of the wheel flanges against the rails. With very heavy loads on the wheels this practice may be avoided by dispensing with the radial axle-boxes and guiding the wheels in another mode, giving free movement to the springs in every direction while using ordinary axle-boxes.

Diagrams Nos. 7 and 8, sheet A, plan and elevation, show this arrangement. The ordinary axle-boxes are fitted with strong clips passing round them vertically, and connected to pivoted shackle-bars of great strength; the other ends of the shackle-bar are pivoted to the frame of the engine or carriage in such a mode that the ends of the shackle-bars on the two opposite axle-boxes are 18 inches to 2 feet narrower together than the other ends are at the frame. The result of this is that as the flanges of the wheels press against the rails or curves to right or left, the axles are, by the action of these shackle-bars, put out of parallel with the rectangular cross-line of the frame, and assume positions truly radial to the curves, the shackle-bars serving as guides and retainers to the axles with much greater strength than the ordinary horn plates, which are dispensed with. The bearing springs are pivoted on the

top of the axle-boxes, and carry the load by means of long suspending rods, the upper ends being hemispherical, and resting in cupped holes in the spring plate, provided with oil. The lower end of the suspending rod receives a nut of a similar form, taking a similar cup on a scroll or bracket attached to the carriage frame. Thus the top of the rod with the springs can move in a radius of six inches, giving free movement to the wheels acted on by the pressure of the flanges against the rails under the guidance of the shackle-bars. And the gravitation of the load upon the springs will always tend to keep the suspending rods vertical, and the axles at right angles when on straight lines of rail, yielding to the pressure of the flanges against the rail curves when required.

As before mentioned, the greater the number of the driving wheels, the greater may be the power of the engine. For some time four driving wheels was the limit, then six obtained, and the load on them was gradually increased to obtain power. Then cylinders were applied to the tender by Mr. Sturrock for the purpose of converting tender weight into engine power, thus making a 12-wheeled engine capable of working two cylinders or four at pleasure.

Some heavy tank engines have lately been introduced with eight driving wheels, all connected by coupling rods, the end wheels being enabled to slide laterally across the engine frame to the extent of five-eighths of an inch to either side by the pressure of their flanges against curves of the rails, and credit is taken for what is called an "apparatus of translation;" in other words, for the use of spiral springs placed horizontally parallel with the axles for the purpose of keeping the wheels central or centre-seeking when on a straight line. The defects of these tank engines are several. The amount of movement on the end axles only corresponds to a curve of $7\frac{1}{2}$ chains radius, and with the axles abnormal to the curve, while the total weight of the engines, 56 tons upon eight wheels, is crammed into a length of 15ft. 3in., being at the rate of 7 tons per wheel, and 3 tons 14 cwt. per foot run of rails. Such a concentrated weight must seriously damage the permanent way and severely try the bridges. It is true that better rails and stronger bridges may be arrived at, but with greatly increased cost, and it is better to distribute the load over a larger area.

There are ten driving wheels, the six internal being as the ordinary six-wheel goods engine, connected by coupling rods, the middle wheels being without flanges. The four end wheels are radial, and have a lateral traverse of four inches to each side. They are connected to the driving wheels by friction wheels, pulled up between them from below by screws acted on by pinions or worm wheels, which may be tightened or loosened by the driver at pleasure. Very small pressure is needed, as the friction wheels act as wedges at an acute angle between the other wheels, and the action is on the periphery instead of on a crank pin, between periphery and centre. The fire box is 11 feet long, and has 300 feet of heating surface. A tank in front is attached to the smoke-box with a through tube, which serves to heat the water and give access to the small tubes, the smoke-door then being placed at the end of the tank, which holds 2,000 gallons of water. The fuel bunk behind the fire-box has 60 feet cubic of space. The space for the driver and stoker has 40 feet super. The total weight is 60 tons, or 6 tons per wheel, and the total wheel base being 28 feet, gives a load of 2 tons 3 cwt. per foot run of rails. All the wheels have spring tires, both bearing and friction. The total length of the engine is 40 feet over buffer beams, and it will roll round curves of $3\frac{1}{2}$ chains radius. This engine should be equal to a load of 420 tons up 1 in 50 at 20 miles per hour.

In making steam the important question is what fuel is used. Coal with abundant hydrogen is a better material than coke or anthracite without hydrogen. The reason is a very obvious one. The heat must be brought into contact more or less direct with the heating surface. Where red fuel without flame is used, the connection with the heating surface is through the medium of heated air. But it is not practicable in a fire-box to heat air to the intensity of flame, nor will air communicate the heat so freely. But if the flame can be produced in quantities so as to cover the whole heating surface of fire-box and tubes, and thus cut off all access of air, much more heat can be applied to the metal and absorbed by the water in a given time, and thus a boiler may be doubled in its steam-producing capacity. If properly applied, petroleum would probably be the best fuel, as it would supply pure flame; sprays of petroleum being forced into the fire-box with air under pressure so as to produce perfect combustion without smoke. In fact it would be a huge paraffin lamp, with the great advantage of getting rid of dust and dirt, probably tripling the duration of fire-box, tubes, and boiler, besides preventing the cutting of the machinery by particles of coke, with the facility of exactly adjusting the heat to the demand, and keeping up steam when required without opening or closing the fire door, just as a gas-jet is turned up or down. We must work in this direction before the locomotive will cease to be a nuisance.

In using radial axle-boxes for engines, with the friction of the spring bases on the box tops under heavy loads, there is no trouble, for the care of the engine involves an almost constant oiling process, and the oiling of the spring bases can be simultaneous with the axle-bearings; but with wagons apt to stand aside and be neglected this might be disadvantageous. For this purpose the plan of radial shackle bars would be preferable, as involving no necessity for care. That carriages with

radial axle-boxes will do very well, has been sufficiently proved on the Hartlepool line; but in all cases of radiation with six-wheel carriages, provision must be made to keep the central wheels true to the gauge while the end wheels radiate. Curvilinear axle-beds may also be used as wheel guides with common axle-boxes (see Diagrams Nos. 17, 18, and 19, plate A).

When very large carriages are required for heavy loads, eight-wheeled vehicles are best, and in such case it is better to group them in fours towards the extreme ends, providing for the true radiation of the wheels and axles to curves. The structure of American long carriages is familiar to most of our readers. A body some 60 feet in length, with entrances at each end and seats along the sides, leaving a central passage way, accommodates about 60 passengers, or a passenger per foot run. Practically there are two doors for 30 passengers each, and for a quick-worked metropolitan line this allowance would be scarcely found enough for rapid work. This long body is placed upon two four-wheeled frames called bogies—one at each end, with a central pivot to each, so that the bogies may swivel beneath them by an impelling force in any direction. These bogies are supposed to be guided by the rails against the flanges, and so they are; but inasmuch as the axles are for the most part very close together, as the leading wheels impinge on the outer rail of a curve they recoil, and the axles, instead of taking a position truly radial to the curve, become misguided and abnormal to the curves, and the machine becomes a sledge against the rails, as may be known by the grinding and jarring, and the effects of wear. To make them run moderately true under these conditions, the bogies require to be lengthened, and the axles kept as far apart as those of ordinary wagons. In fact the bogy system is practically neither more nor less than the ordinary railway timber carriage—a long body stretched over two wagons. To make the bogy act properly requires that the wheels should be truly guided, with the axles normal to the curves or straight lines. Moreover, the structure of the bogies necessitates the use of wheels of small diameter, and a generally inefficient mode of springing. Diagram No. 12, plate A, illustrates the application of a guiding principle without diminishing the diameter of the wheels, by the construction of under frames.

Two pairs of wheels at each end of the carriage are connected four feet six inches apart by iron bars bolted to the top and bottom of ordinary axle-boxes. Between these bars and between the wheels is bolted transversely to the carriage and parallel to the axles a strong wide wooden beam. This constitutes the under frame. On this beam is bolted a strong flat iron, in the form of a quadrant, with a central pivot-hole above the axle nearest the carriage centre, and at a sufficient height to give ample play to the bearing springs without the quadrant iron touching the body above. The radius of the quadrant curve struck from the pivot-hole is sufficiently long to project it clear of the beam. A central pin from the upper frame passes through the pivot-hole, with power for rising and falling by the bearing spring action, and a pair of curved angle plates bolted to the upper frame in front clip the curve of the quadrant between them, like fore and aft horn plates, perfectly securely, but with provision for curvilinear movement. Bearing springs are placed on the wheel frames, two on each side, and the body is suspended on them by the long swinging rods or shackles before described. It will be seen that thus the inner axle and wheels nearest the centre of the upper frame are a pivot on which the outer wheels swing round with the axles normal to the curve, when pressure takes place on the flanges of the wheels. And end guards are applied to the boxes of the inner axle from the frame, to prevent the frame from altering its position length-long the axle when passing round curves with the outer rail greatly elevated. There remains just so much want of truth in the radiation of the axles as the distance between them amounts to, which is not much in 4 feet 6 inches, even on the two-chain curve, which the carriage is fitted to run round—i.e. the convergence or divergence of two lines 5 feet long on a radius of 132 feet. But whatever it may amount to can be easily compensated for by the use of sliding spring tires.

A carriage (see Diagram 12, plate A) 54 ft. long by 9 ft. wide may thus contain 12 bodies for 12 persons each, third class—total, 144. The same sized frame may carry 10 second class, with 100 passengers; and a similar frame 8 bodies for 64 first class passengers. This gives an area of $3\frac{1}{2}$ square feet for each third class passenger, $4\frac{3}{4}$ for each second class, and $7\frac{1}{2}$ for each first class; and this is the consideration which should govern the proportioning of fares.

Comparing this with the American carriages, we find that in a length of 180 feet of train 180 passengers are carried, all one class; while in the carriages above described, 308 passengers are carried in a train length of 162 feet. And while the Americans number 30 per doorway for exit and entrance, this improved system gives 12, 10, and 8 per doorway—a manifest advantage in rapid passenger traffic.

Assuming the ten-wheel engine before described to be capable of taking a load of 650 tons up an incline of 1 in 100, this system would facilitate the transport of 5,000 passengers in a single train—a very important question to consider when the conveyance of troops, whether volunteers or regulars, is concerned; and a very important consideration for railways where the traffic might be doubled but the trains are too frequent.

In the construction of trains a very important element is the friction of axle bearings, and the minimum of friction is obtained by the use of good lubricating oil instead of viscid soap. The use of the latter originally obtained as a compensation for inferior mechanical

structure. The viscid material enabled axles to be used of smaller bearing surface than could be used with oil, which can only maintain a cushion with ample surface. As axles are usually constructed, the bearing brass is held between two raised collars of the axle. This is a disadvantage to begin with, as it is the tendency of the lubricating fluid to ascend to the largest diameter, just as the strap of a machine works to the highest point on a drum wheel. And thus the grease or oil in a railway bearing works out to the shoulder collar, in spite of all contrivances to arrest it by leather shields and collars, and other futile work. And at the same point the dirt and grit gets in; and as this small surface of collar has to sustain the whole shock of the blows of the wheel flanges against the rail, rapid wear ensues.

By Diagrams Nos. 13 and 14, plate A, the axle is shown with a centre collar, and no end collar, and the bearing brass clips over this collar without touching the shoulder next the wheel. It is thus in a position to carry up the oil, and be perfectly shielded from dirt. The oil is contained in a cup below the axle, with the edges passing into a groove of the brass bearing, and the ends fitting tight to the axle, which is thus contained in a bath of oil nearly up to the middle diameter. The cup is held up by a spring acting on a wooden block at the bottom of the box, and by an opening the cup can be removed for cleansing. Oil can also be applied from the top of the box, which will pass into the cup below. As the brass wears, the spring keeps the cup up to its work. Curled horsehair or other waste may be kept in the cup till it wears to an exact fit.

In using long and heavy trains facility of traction is most important in diminishing the strain on the traction apparatus; but there is another question to be considered—the brakes.

All rapid movement which is not destructive must be of gradual increase and as gradual decrease. Even a cannon ball, if discharged by a gradual expansion of gases, might start from rest with as little destruction as a spent ball. The force which is needful to attain rapid movement must go on accumulating till the full speed is attained, when a lessened amount of force will serve to keep up the speed to the maximum. If by any contrivance that speed could be suddenly arrested, the force must pass into the body arresting it at the risk of destruction, unless a sufficient amount of elastic yielding were provided, just as a cricket ball which would fracture a skull is arrested by the elastic yielding of the hands and arms; or as a boy's marble in rapid movement is checked by a marble at rest, which takes up the motion lost by the other; or as a limited number of highly elastic spheres placed in contact in a line will on being struck by a similar sphere in movement arrest it, and deliver the force through the whole number, till the last takes up the movement which has been lost by the first.

In a railway train the surplus force required to attain speed is called "momentum," and it will take the same time with the same resistance to absorb the momentum as it takes to create it. Or with increased resistance the time may be lessened. The circumstances of railway working with frequent trains require that the momentum be arrested in the shortest time possible, and that the arrestation be under the control both of guard and driver, and more especially of the latter. The means of arrestation has in almost all cases been confined to the pressure of wood blocks against the peripheries of the wheels, with more or less force, dependent chiefly on the judgment and skill of the guard. That judgment has been mostly in favour of applying as much force as possible, in order to prevent the wheels revolving, the result being that the wheels skid on the rails and grind flat places, with, on the whole, a less retarding effect than would be produced by friction between brake-block and wheel, while the form of the wheel is destroyed and great mischief produced.

The earliest brakes used in railway wagons were cranked levers armed with a block of wood pressing on one wheel out of four. This arrangement required each wagon to be man handled, and was obviously not adapted to fast trains in rapid motion. When fast passenger trains began to run, brakes were applied to first-class carriages as being the heaviest, and a guard outside worked them from the roof, the guards being increased according to the number of the carriages. In this arrangement, the brake-blocks were suspended from the frame, and pressed against the wheels by cranked shafts drawing or pushing rods in opposite directions. When the brake-blocks are loose on the wheels they chatter and make much noise, but when tight the action of the spring is prevented and the passengers annoyed by roughness, as though riding in a cart. By another arrangement this difficulty was sought to be avoided: this was fixing a longitudinal bar to each pair of axle-boxes, and placing slides on it to carry the brake-blocks by the same process as the hanging brakes. But neither was this satisfactory, and finally the brake-van came into use, carrying the luggage of the passengers, which was supposed to give weight enough for the adhesion of the wheels to the rails, by the application of the brake-blocks as before described. In a large train three brake-vans were placed, one at the back of the train, one next the tender, and one in the middle, requiring of course a guard to each.

Still this was not satisfactory, and attempts were made, with more or less success, to apply brakes to all the carriages of a train, working them from the end, the usual brake-blocks suspended by hangers being used. One method was to wind up a spiral spring on each carriage, and, when needed, to discharge it by a trigger communicating with the guard. Another method was

to connect a series of brake rods from carriage to carriage along the whole train by a system of toggle joints compensating for the play of the buffers. In both these cases the ordinary suspended brake-blocks were used, the apparatus being an improvement in the mode of applying them. In the case of the spring it was a secondary application of human force, to be renewed as often as the brakes were discharged; and in the other it was a severer task to apply the brakes, because the whole force had to be used simultaneously instead of carriage by carriage, as in the case of a spring. Another method used successfully on a metropolitan line was to connect several carriages by a chain passing from the brake-van and wound up by the guard, the varying lengths by the action of the buffer springs between the carriages being equalised by jointed bars carrying sheeves, and thus preserving the same amount of chain action under all conditions. Still, as the stations increased on the line, the importance of stopping rapidly increased, in order to work to time, and that a very short time.

The next change was to employ a very long chain through the whole length of the train, hanging in a festoon as bight below each carriage. The whole chain passed through running sheeves attached to the frame, and as the chain was tightened up to a straight line every pair of hanging brakes on each carriage was pressed simultaneously against the wheels with a gradually increasing force, and without necessarily stopping any of them, thus producing sufficient friction to arrest the train, even against the whole force of the engine. To perform this operation a very considerable force was needed, quite beyond manual power, and so a very ingenious plan was resorted to of using the momentum of the train to arrest itself. A pair of friction wheels were suspended from below the guard's brake-van, three to four inches from the running wheels. These wheels carried a barrel on which the end of the brake chain was wound. By bringing these friction wheels in contact with the running wheels by hand, for which purpose a very small amount of power was needed, the friction caused the suspended wheels and their barrel to revolve, and so wind up the chain and put the brake-blocks on to the wheels by tightening up the bights. When the pressure of the friction wheels against the running wheels was removed, weights on the chain at the centre of each carriage brought it again into the festoon form and the brakes were free.

In the preparation of plans for radial carriages the writer had to consider how to arrange them to follow radial wheels, and that point ascertained the next question was as to the general conditions required in a perfect system of brakes, which are as follows:—1. The brakes to be continuous through the whole train. 2. To be self-acting but under the control of both guard and driver. 3. To be connected to the axle-boxes or frames on them and not to the body. 4. So to be arranged that guard and driver might divide the train between them on applying the brakes to more or less carriages, as might be deemed desirable. 5. The brakes to come into instantaneous self-action in case of a train separating on an incline. 6. That every individual carriage when left on a siding might have the brakes on or off at the pleasure of the porters.

With regard to the continuity it may be remarked that one difficulty has been the varying lengths of the train by the collapse of the buffers. This has been usually overcome by shortening the stroke of the buffers and diminishing the collapse, and provided the connection of the brake chains or rods be sufficiently strong to draw the train together all that is needed is attained in that particular. With regard to self-action, there is the choice of two means—gravity or spring power. The writer prefers the former. But there is this consideration, that while the pressure is ample on the wheels, it is necessary to remove as much weight as possible from the acting power. The weighted lever or steelyard beam, with a long limb and a short one, furnishes this desideratum. This weighted lever then will be self-acting, but it is necessary to put it out of action at times. For this purpose it is necessary to use the principle of the common sash window, a counter-balance weight just so much greater than the weight of the lever as to keep the brakes off the wheels. The next question is how to lift these counter-balance weights so as to allow the levers to descend. This is accomplished by a system of continuous rods or bars, with chain connections between the carriages, running over sheeves to permit easy movement, springs being applied to vary the length of the rods to suit the play of the buffers. Thus the weight to be lifted, apart from the friction of the bars, will be only about 5 lbs. per carriage through about a foot space, and about 60 lbs. per carriage through an inch space, to have the full pressure of say 5 cwt. on the four wheels. The total run of the rods longitudinally would be just the space of lifting the counter-balance weights vertically. To leave the brakes free to act in case of the couplings breaking accidentally in working inclines, it is only needful to be able to fix the counter-balance weight out of action on a sliding bar, and keep the brakes suspended by guard or driver, each taking half. If taking the whole, and supposing a train of twenty carriages, the total load to lift would be about 11 cwt., against the total brake-power of five tons on the peripheries of the wheels.

The Diagrams Nos. 5 and 6, sheet A, show in plan and elevation the simple mode in which this is worked out. The springs are omitted for the sake of clearness.

Half of a long carriage is shown with a front wheel underframe and quadrant plate. On the central cross timber are bolted a pair of tunbras parallel to the wheels, and carrying the brake-blocks, so that in radial action the brakes move with the wheels. The brake-blocks are

connected together by two bars, one at the top, the other at the bottom. From these bars, attached at the centres, project two longitudinal bars connected together and forming a long lever, the end of which farthest from the brakes is held up by a chain, with a counter-balance weight passing over a sheeve transverse to the carriage frame. This counter-balance weight keeps the brakes off the wheels. On the lifting of the counter-balance weight by the longitudinal rods, pulled by either guard or driver, the brakes press on the wheels. These longitudinal rods may be connected together throughout the train, thus applying brakes to every carriage. To provide for the action of the buffer springs, the rods that govern the brakes are divided into two lengths by springs slightly in excess of the force required to lift the counter-balance weights, so that elongation may take place when needed. Thus the brake power may be divided between guard and driver by leaving the rods unconnected at any part of the train, and in case of accidental severing of the couplings on an incline, the brakes will, if the counter-balance weights be suspended out of use, be instantly pressing on the wheels of the detached portion of the train. That is to say, in ordinary cases the counter-balance weights keep the brakes off, and on steep inclines the guard or driver keeps them off. It is obvious that these long carriages offer a great advantage in carrying the brakes directly on the wheels, and in permitting great length of lever. With shorter carriages the brake-blocks may be attached to levers projecting downwards from the axle-boxes, and with the levers at the upper portion above the axles pressing them into contact with the wheels, as shown below by Diagram No. 15, sheet A.

A very ingenious system of working brakes is now on trial on the London, Chatham, and Dover Railway. Air-pumps are worked by means of piston wheels in the running wheels of the carriages to charge a reservoir with compressed air. This air is admitted to a cylinder below each carriage, and pressing on the piston, communicates the power to the brake levers. This system promises well, if the working surfaces can be kept in order and sufficiently air-tight.

There has been much discussion as to the best means of communication between guard and driver, but it all resolves itself into the question how to obtain a convenient passage way through the train, which is the American method. If the carriages were constructed nine or ten feet wide inside there would be no difficulty. A passage in the centre 1 ft. 9 in. wide through a first class would leave space on either side for enclosed cabins holding four persons each, with sliding doors opening into the passage, and with folding doors externally, as usual. The passage would also be accessible from the end platforms. The second class would only need a central passage for the guard's legs between the seats, 12 inches in width, leaving space for three passengers on each side; and the third class would not need a passage way, but simply sliding doors at the ends, like the first and second, to form through communications (see Diagram No. 16, sheet A).

THE RATIONALE OF THE SEWAGE QUESTION.

After all the cost of the great Metropolitan sewers, it is by no means a settled question whether the dry method or the wet method be the best in dealing with sewage. So far as regards sewage which largely consists of water, it must of course be provided with conduits to carry it away; but as regards solid matters, it is probable that in the long *run* water added to them in large bodies will by no means prove the cheapest carrier. It is a very easy thing for those living by the side of a running stream to throw into it any dirt that will *float*, as a lazy method of dealing with it; but if the stream had to be provided artificially, by pumping up, it would soon be found a very costly process, and by no means the best.

Let us begin at the beginning. Of what does sewage consist? The refuse of matter brought into the great towns and cities, to be consumed by the inhabitants as food, or fuel, or for cleansing purposes. General refuse is a far more extensive matter—some noxious and some innoxious. Refuse of building materials, as brick and stone, mortar and cement, are continually accumulating, and go to elevate the general site of a city, because being innoxious they are not carried away. Coal used as fuel disappears in gaseous forms, save a very small residue which is perfectly innoxious other than as dust, and is used in making bricks and for other purposes. Of the food consumed, the large mass that passes through human and animal bodies is converted into gases like the coal; and the refuse consists of uneaten substances such as bones, and the fæces ejected from the bodies, as well as the urine, which is merely water impregnated with animal and vegetable matter, and chemical salts. There is also the refuse of uneaten vegetables. In addition to these, there is the fouled water mixed with soap, used for cleaning purposes, and the water used in cooking. To add to this, we have the refuse from gas-works and manufactories, chemical and mechanical, generally.

As a general rule, chemical and manufacturing refuse, as well as the refuse of food capable of becoming

noxious by exposure, are mere waste capable of conversion to purposes of utility. Whenever a substance exists incapable of conversion, it may generally be assumed as innoxious just as much as sea sand; if capable of chemical conversion, it simply denotes want of knowledge if it be not so used. Dust-holes and dust-bins are generally considered synonymous with gaseous nuisances; yet it is not coal-dust that creates the nuisance, but only the animal and vegetable refuse that is mixed with it—such as bones and cabbage-leaves with sufficient moisture in them to induce fermentation; and if such substances were dried till the moisture were out of them, they would in that condition be harmless. If valuable for sale, for manure or other purposes, they should be dealt with day by day—either put into furnaces to be destroyed, or into retorts to produce gas for illumination. The practice of accumulating such matters for weeks together is a bad habit, which should not exist. As for water being essential to carry away refuse, it is a farce. If the rows of houses were all constructed so as to have a back access to the receptacles of dust and fæcal matters, there is no reason why these receptacles should not be so constructed as to be cleaned out daily and nightly. The real great nuisances are the fæces and urine, and their bulk and weight are scarcely worth considering. An infinitesimal proportion of the means of transport required for bringing the daily food into a city, would suffice to carry away the fragments ejected from the bodies. But if the results of a year's provision are left to accumulate, the question then, and only then, becomes serious. Two things are required,—that the accumulations should never go on for more than twenty-four hours, and that they should be deposited in places accessible to air and light, and as convenient as our pantries and meat-safes. If the previous day's coal-dust were deposited every morning in a shallow slate tray, and the closet were constructed, as it might be, to receive on the coal-dust all the fæcal matter, and to conduct the urine away to a separate receptacle, and they were treated with deodorising material at the time of taking away, there would be no perceptible nuisance to the inhabitants of the houses, nor would they ever be conscious of the process, save by freedom from trouble as well as nuisance. And the due discharge of the scavenger's duties would be ensured by ocular demonstration of all the inhabitants, when a light receptacle was substituted for a dark one. As regards the urine being conducted into large tight cisterns underground, it could be again raised on the syphon-exhaust principle into barrels, and carried away for agricultural purposes, being in truth the most valuable part of all the sewage-manure.

There would be no difficulty in all this arrangement were the houses only constructed, for facility of access, with the closets external to the dwelling, and with proper chimney-pipes to the receptacles. The introduction of closets direct into houses has been a grievous blunder, aggravated by the system of close sewers and drains; and were we to begin *de novo*, we should probably alter these conditions.

Time was, and still is, that houses built in rows had each a front court or garden, and a back court or garden. In this latter were dug two holes, as far apart as the space permitted. One was the cesspool or privy; the other, the well or water-supply, being of much greater depth than the other. If the soil were pervious, the liquids of the cesspool filtered into the well, and supplied organic materials to it; but as people did not then know generally, nor know yet universally, that such a mixture is injurious to health, the process went on, and goes on still, with a thick population, cropping out in occasional epidemics. When water-supply from distant sources became the work of public companies, most of the wells disappeared, but the privies remained; being large holes in the ground, holding probably a seven years' product of the solid ejections of human bodies, the fluids having contrived to flow away by irregular channels. The water-closet was invented to stop the effluvium of the cesspool from entering the apartment, by the arrangement of a water-valve, and with an efficient chimney to the cesspool—the whole being external to the house. The result was found to answer: the overflow carried off a considerable quantity of the soil, and the rest consolidated at the bottom. It is true that by law no one was allowed, under a considerable penalty, to make a communication between his privy or water-closet and the sewers; but as the general house-drain went into the sewers, it was very easy to effect the communication surreptitiously. There was no one to discover it but a rough kind of man, who entered the sewers to inspect them, and black-mail overcame that difficulty. The writer remembers a case where a sewerman came into a tradesman's shop in the Strand, to inform him that his soil-drain opened into the sewer. "Impossible!" replied the tradesman; "I have the plan of it in my parlour behind the shop." In went the sewerman and the tradesman, and the plan proved to be a small sheet of very crisp paper, with the name of "Henry Hase" written at one corner. The plan was convincing, but required inspecting anew from time to time.

Water-closets went on increasing; they cleansed themselves with little trouble, and people thought they had lost the obnoxious matter, buried it in the ground somehow, out of sight, anyhow; and so in time an Act of Parliament was made encouraging the extension of water-closets, and enforcing their communication with the sewers under a penalty. The contrivance was admirable, if only there had been a bottomless pit to empty them into. But the River Thames was the receptacle for London, and that had a bottom, and the "thick and slab" material collected therein increased year

by year, and was churned up and mixed by the steam-boat paddles. In the summer and autumn months, when the thermometer in the air rose to 75° or 80°, and in the water to 60° or 65°, there commenced first an acetous, then a vinous, and finally a putrid fermentation. There was no mistake about the stench and nuisance: all London rang with it, and when at last it penetrated to the noses of the legislators in the Parliamentary Palace, they took measures to have it remedied at the hands and brains of the Metropolitan Board of Works and their advisers. But the real evil was more in the sensation of disgust than of absolute disease engendered thereby. It was, in truth, a curative process of nature, converting organic refuse into gases, to mingle them with the general atmosphere. And this process, performed in the open air over the general wide surface of the river, was a very favourable condition for the dilution of the gases as fast as evolved. On one occasion the writer had to cross over from the Isle of Dogs to Greenwich, during the height of the nuisance, in a small row-boat, and it was needful to stop the nostrils. A fortnight after he was partially upset in a similar boat, and his clothes saturated with water, but the stench had in the meantime disappeared. The putrescent process had exhausted the material, and precipitated the more soluble portions. During the whole of this time the skippers below-bridge were taking in their sea stock of water from the river as usual, and it is a known common axiom amongst those who go down to the sea in ships, that "there is no water like the Thames water for sea stock." When put into the hold, the warmth of the vessel gradually sets it fermenting, the putrid process comes on; and in about three weeks everything organic has been thrown off in gases, the unchangeable precipitate falling to the bottom, when the water becomes perfectly pure and agreeable to the palate. Just such is the process that takes place in the river, when sun and warmth lasts long enough—very unpleasant while it lasts, but finally ending in purification, with the advantage of the free escape of the gas into the upper atmosphere.

Now, the result of the main-drainage is to take this process away from the river. It has literally removed the nuisance, but it has not abolished it. On the contrary, it has carried the process of putrefaction or distillation into the closed sewers, in which there is always warmth enough to keep up the constant evolution of sewer-gas. And as this sewer-gas can only get away by the process of levitation, just as water gets away by gravitation, therefore as fast as generated it rises to all the upper levels under more or less pressure, escapes when it can through the street-gratings, and penetrates into houses through every pipe and closet that is not perfectly stopped (water-closet, sink, drain, or other), and there is scarcely a building throughout London that is not filled with the stealthy odour in every hollow of floor or partition. It ascends the sewer-pipes, passes through crevices in the walls, nestles beneath *hearthstones*, and oozes through the cracks in the skirting-boards, and comes by the chimneys in down draughts, and into the garret-windows. At badly-formed joints of the rain-pipes it rushes out and upwards, and may be traced by the rust.

As regards the result, it must be, practically, more mischievous than when discharged in the river. Admirably as the works of the main-drainage have been executed, and favourable as the result has been to the river, we have not yet come to the end of the question. If the distribution, on the Maplin Sands and elsewhere, should prove to be a failure, and the sewage should again run into the river, in default of any other outlet, a huge black shoal will gradually arise below Barking, aggravated by the salt-water, and effectually prevent travelling salmon from ascending and descending.

The first result of sewage irrigation will no doubt be successful, but it is still a problem whether sewage irrigation can be constantly poured on *land, without likening* it to the condition of rice-swamps, which produce the largest crops in proportion to their noxious effect on human health. The "Foul Burn" of Edinburgh, the great sewer fetish worshipped by sewage doctors, has not been favourable to the health of the surrounding inhabitants, and other localities tell the same tale.

Whether we shall eventually construct our houses so that we may have no more trouble or nuisance in carrying off the detritus of our bodies than in depending on the provinces and other countries for their supply, so as to make a thickly-peopled town as free from mephitic gases as a sparsely-peopled country, is yet a problem; but meanwhile we must deal with the existing evil, the huge volume of sewage as generating from minute to minute, and which will not be quiet below like the carbonic acid gas of old wells, but will ascend as sulphuretted hydrogen ever does. The only apparent remedy is by the construction of lofty ventilating-shafts of ample area, close enough together to arrest the gas, and entice it upwards without much horizontal haul. These shafts would require to be upwards of two hundred feet in height, and some twenty feet in internal diameter. It may be objected, first, that they would be ugly, and look like factory chimneys, though the answer to this is that ugly factory chimneys would be less ugly than a fœtid gas atmosphere; but inasmuch as no smoke would issue, there would be scope for architectural devices, and possibly some changes in artificial lighting would enable them to be used as lamp-towers. If cheapness be aimed at, coloured bricks will supply it; for whatever the diameter of the shaft, a single brick in thickness is amply sufficient, the internal form corresponding to the external; being a truncated cone of the same angle in all cases, and only varying in the diameter of the base, which is increased or diminished to suit the

height. The only really important objection is the value of the land occupied by the erections. But whether this be much or little, the more important consideration of the health of city indwellers must ever be held paramount.

There is another point to consider—whether it is possible to utilise the sewer-gases for agricultural purposes. The most valuable part of all manure is that which is capable of being taken up by water, or of being converted into gas. It would therefore be worth experimenting to ascertain whether the absorption could be economically induced by flocculent peat or charcoal, at intervals along the whole length of the line. It is found advantageous, on the score of abating nuisances, to use charcoal baskets for the gas to pass through at the ventilating openings in the mid-pavement of streets; but it is not yet known whether charcoal, when taken up fully saturated, would or would not be a valuable manure—whether, in short, it would pay to convert the sewers into factories for artificial manure, impregnated by the gaseous process. If it would, the question would be solved, and the propagation of diseases by the use of liquid manure, which is a very probable evil, would be largely if not wholly prevented. Meanwhile the evil is pressing upon us daily, and more and more heavily, and it is of no use striving to bury aëriform fluids in underground tanks. It is seeking to contravene the laws of nature. Nor is it of any use to build a solitary tall chimney, in the hope that great lengths of sewers may thereby be drained of gas; the chimneys must be as frequent as the present ventilators, or the gases will continue to take short cuts through the houses, as they do at present. Upon the details of this question the best information may be obtained in the able report of Mr. Haywood, the Engineer to the City of London, published in 1858, at the instance of the City authorities—eight years in the life of a generation that has been too obtuse hitherto to appreciate, digest, and absorb it, and put its recommendations into practice.

The advent and constant increase of underground drainage is a process constantly tending to diminish, not our water supply, but the stock of water in store. Bogs and ponds and lakes are nature's processes for storing up water. Irish rivers depend mainly on Irish bogs, and to drain these bogs would be to dry up the rivers. Some countries have to depend on perennial snow. The modern floods of the Rhone, which occasionally wash down houses and streets of French towns, result from increasing avalanches of snow in Switzerland, which, formerly sheltered by pine forests, stored up the snow throughout the year, and gave forth a constant measured supply to the rivers. The cutting down of the timber has converted the Rhone into an alternate mountain torrent and a dry bed, and it would not surprise us if some day Louis Napoleon were to set forth as a serious reason for the annexation of Switzerland that no otherwise could he follow the dictates of nature in providing for the due utilisation of a great French river.

By our processes of agricultural drainage almost every shower that falls reaches the sea in the course of a few hours, and is so far lost to us, for want of artificial interception to compensate for this loss of national interception. If London is to go on increasing at the present rate, Thames water will not supply our sewage washing demand, and we must perforce go back to the dry system. In a natural condition of a country, with animals and human beings scattered, we do not need sewers, for there is a natural distribution of manure. In the aggregated condition of cities artificial distribution is needed, and in the dry system rightly managed will be found the cheapest and most effective process for the prevention of nuisances.

HISTORY OF THE DRAINAGE AND SEWERAGE OF LONDON.

WHATEVER may be the pre-arranged system adopted for providing proper and effectual sewerage in the formation of towns in the present day, when it is known to spring into mature existence and active operation in a few years, and when the want of a comprehensive plan is so much felt in old towns, it is quite clear that facilities for drainage or sewerage of any description formed no element in the choice of a site for the formation of a village or town in its infancy. In the early days of society, and amongst the uncivilized portion of humanity, it may be doubted whether a spot upon which to build a village, or upon which a tribe or large family could make a settlement, would be deliberately and considerately chosen otherwise than with a consideration of present wants, the avoidance of present danger, or the following of some particular occupation.

The nucleus of the present widely-extended city of London may have been nothing more than a few fishermen's huts, as the Thames, before its being polluted by the sewage of an immense population, was doubtless well stocked in its several reaches with salt and fresh-water fish. The site of the ancient London, confining its area within reasonable limits, is by no means ill-chosen—placed on an elevated spot on the banks of a navigable river, at a distance of between forty and fifty miles from the sea, giving a reasonable security

against foreign invasion, with an ample depth of water up to the town for the accommodation and development of an extensive trade. The present extent of London could not possibly have presented itself to the founders of the city in the most shadowy form, as it cannot be supposed that the Thames was embanked at that early period; and consequently the whole of the flat country on the south side of the river from Putney to Greenwich, now nearly covered with houses, would then be covered with water at every *high* tide.

An authentic history of the embanking of the River Thames would doubtless be very highly prized, if such could be discovered. The works are among the oldest and most important engineering operations in the kingdom, considering the remote date which must be assigned to them. It can hardly be conceived that works of such magnitude, and executed with such skill, could have been constructed before the period of the Roman occupation. Previously to confining the waters of the Thames within the present banks, the site chosen by the original settlers of the modern London was the only place which could be selected on the north bank of the river near deep water, and raised sufficiently high above the influence of the wide-spreading tidal wave. The River Lea, situated on the east, flowing into the waters of the Thames, extending over the Essex marshes, afforded protection against any inroads from that quarter, if such were anticipated. On the west, the Fleet Valley, with its wooded banks and its limpid stream, flowed down in purity from the elevated grounds of Islington, Hampstead, and Highgate, a "thing of beauty," but not a "joy for ever," as it has passed through many phases which have been neither beautiful nor fragrant since the nucleus of London was formed on its eastern slopes.

The earliest records connected with the drainage of London that can be obtained, carry the history as far back as the reign of Henry VI., A.D. 1429, when an Act was passed which recognised the pre-existence of Commissioners of Sewers, and empowered them to "execute their own *ordonance*." In the reign of Edward IV., A.D. 1472, an Act was passed "For the taking away of Fishgarths;" and in the reign of Henry VIII., A.D. 1531, "The Bill of Sewers with a new Proviso" was enacted, which became the basis of legislation up to the modern era of drainage agitation, in the first quarter of the present century.

This last Act was only passed for a few years, but continued from time to time with slight alterations; and in the subsequent reigns of Edward VI., Elizabeth, James I., and down to the reign of George III., in the year 1812, several Acts were passed defining the powers and enlarging the jurisdiction of successive Commissions of Sewers, without making much progress towards the development of a good system of drainage. The subjects of water-supply, paving, lighting, and cleansing, seemed to crop up gradually during the above reigns, and considerably complicated and confused the whole subject.

If it be at all necessary to distinguish between drains and sewers, the former may be considered as receptacles for draining the ground, and for carrying off the surface water; and the latter to receive and carry off, in addition to that carried off by the drains, all refuse from house-drainage, and impurities of every description; consequently, in this sense of the terms, there could have been no sewers in London prior to the year 1815. Up to that period it was penal to discharge sewage or other offensive matters into the drains. Cesspools were regarded as the proper receptacles for house-drainage. Subsequently, it became permissive to turn the house refuse into the street drains, and in the year 1847 an Act was passed making this system compulsory.

Cesspools as receptacles for all the refuse from one house, or from any number of adjoining houses, are highly objectionable for many reasons. They are generally in too close proximity to the houses, and seldom if ever built water-tight; consequently, the liquid portion of the contents permeates the soil round the houses, and frequently finds its way into the neighbouring wells, the well-shafts forming a line of least resistance, or convenient drain to draw off the surplus saturation from the surrounding grounds. The wells were consequently contaminated with diluted sewage, and consequently fatal results to those using the water inevitably followed. The volatile gases from the decomposed mass of sewage in the cesspools found their way into the houses, more particularly before the introduction of improved water-closets and trapped gullies, and proved very injurious to health and comfort. The extremely disagreeable process of emptying cesspools was also highly objectionable, and it seems difficult to conjecture how the system was tolerated so long.

The laws of science, like the laws of nature, of which they are but the correct reading, are so blended and so dependent upon each other, that they must advance together. The danger to health from the cesspool system could not therefore be made sufficiently evident to insure its total abandonment, until chemical science had arrived at sufficient perfection to make a correct analysis of the water we drink and the air we breathe, and until it was found necessary to employ it for that purpose.

Previously to the year 1847 the sewers of London were placed under the management of eight distinct Commissions, acting with the most perfect independence of each other, and no doubt frequently in the most direct antagonism to one another, and apparently with the most fearless disregard of science. This appeared very obvious where the several systems joined each other, as the sizes, shapes, and even the levels of the sewers were often very variable. Larger sewers were made to discharge into smaller ones; sewers with upright sides and

circular tops, with circular or flat inverts, were joined to egg-shaped sewers; and egg-shaped sewers with the narrow part uppermost, connected with sewers of less capacity, having the smaller end downwards. Variety seemed to be aimed at, and not uniformity of action, and the adaptation of the size of each sewer to the duty it had to perform in the position which it occupied in the general system.

It is quite obvious, however, that so many independent bodies acting over a district which could only be successfully treated as a whole, and without a correct plan of the several districts, with accurate levels reduced to a uniform datum, could only result in confusion and disorder, even supposing all parties concerned to act in unison and with the best intentions.

These several Commissions sought for no other outfall than the River Thames opposite the city, and as the sewage from the upland districts on each side of the river was retained in the sewers in the low-lying grounds near the river for several hours of each tide, they virtually became elongated cesspools. During the period of six years after it became compulsory to convey all house-drainage by direct communications into the sewers, more than thirty thousand cesspools were abolished, and all house and street refuse sent into the river, and that at the most unfavourable state of the tide. The Thames was therefore converted into an open sewer, with its contents not very much more diluted than the sewage in the tide-locked sewers. The sewage being generally sent into the river about low tide, was carried back by the next flood tide, and continued to oscillate for several tides through the heart of the city.

Several of the water-companies took their principal supply from the contaminated portion of the river, and the outcry became loud for a remedy for so great and obvious an evil. It became one of the attractive amusements at the Polytechnic Institution to exhibit the huge monsters which were disporting themselves in the Thames water which was supplied by the water-companies to the inhabitants of London.

In the year 1847 the eight independent Commissions of Sewers were superseded by one consolidated Commission, termed the "Metropolitan Commission of Sewers," the members of which were nominated by the Government. When this Commission came into office it could not but find that the independent action of the eight Commissions, which it had superseded, had led to anything but a satisfactory state of things; and as some of the leading members of the new Commission appeared to possess considerable destructive powers, so far as to exhibit in the most absurd and ridiculous light the piecemeal operations of their predecessors, a report was soon issued making the most of previous defects. The result, however, proved that nature is somewhat parsimonious in the distribution of her gifts, and seldom bestows on the same individual great destructive power to demolish tottering systems and to exhibit them in their worst guise, and at the same time reconstructive ability to devise and build up an efficient and a permanent system to replace those that have been destroyed. The new Commissioners not only arrived at the conclusion that all the practical operations of their predecessors were erroneous and defective, but that these operations were based upon false theory, and that the existing science of Hydraulics relied upon by English and foreign engineers was also erroneous and utterly untrustworthy, as applicable to the operations of this Commission in carrying out what was considered an improved and economical system of drainage for the metropolis. The following extract from the Report of the late Mr. Robert Stephenson and Sir William Cubitt (dated December 11, 1851) shows the opinion of these gentlemen upon the existing state of hydraulic science:—"No part of engineering science has been more industriously investigated than the laws that govern the flow of water in pipes and open channels; and it is probably not too much to say, that the formulæ which represent these laws rank among the most truthful that the professional man possesses. They have been the subject of laborious experimental investigation of the most elaborate character, and their results have been tested by the practical man under every variety of conditions, without their truth being impugned in the slightest degree. The principles upon which they are founded have been sanctioned and adapted by Prony, Eytelwein, Du Buat, and others; and it is to them that we are indebted, in a great measure, for the simple practical form which they present. Our own engineers have modified them to suit particular circumstances, and given them more extensive usefulness. Mr. Hawksley, amongst others, has especially contributed to render the principles which they embrace applicable to almost every variety of condition which the complete drainage of large towns involves; and we shall have occasion, almost immediately, to adduce some instances within the metropolis where the facts confirm theoretical deductions in a very remarkable manner, and lead irresistibly to the conclusion that they may be implicitly depended on."

These conclusions being arrived at, the Commission organised what it called "Trial Works," with the view not only to deduce a new and complete theory of hydraulics from actual experiment, but also to gain some reliable information upon the best practical mode of executing works in brick and mortar, and thus acting upon the supposition that the theory and practice of engineering science in England was so defective that it was necessary to experiment *de novo* upon both.

In experimenting upon any science, such as hydraulics, for example, in order to establish reliable formulæ, which can be expanded with safety considerably beyond the actual range of the experiments, it is well known to all engineers that the most perfect apparatus is

absolutely necessary, that the manipulation must be of the most precise and delicate description, and that the whole process must be under the superintendence of parties possessing the very highest scientific acquirements. That these conditions were all or any of them fulfilled in the Trial Works of this first Commission may be doubted, inasmuch as the immense calculating powers of the Astronomer Royal at Greenwich failed to eliminate reliable formulæ from the whole mass of recorded experiments sent to the Observatory for examination.

Nothing daunted, however, the experiments instituted at the Trial Works were made to result in the production of what has been emphatically called the "small-pipe system," which was strongly advocated by the Commission, and indeed is still advocated by some of the members of this first Metropolitan Commission, as a pet project, to be adopted whenever an opportunity presents itself. It must be admitted that many of the brick sewers in existence in the metropolis when this Commission came into office, were very much too large; but it is only amateur engineers who run from one extreme to a still more dangerous one; as in this case, from a brick sewer, which could hold three times as much as it was ever likely to be required to carry off, to an earthenware pipe, which would carry off not more than one-third of the quantity which might be required to pass through it under certain circumstances. The sewers in the flat districts bordering on the Thames could hardly be too large, as they had to contain the local sewage as well as that sent down from the high land, for several hours during every tide.

Within nine years after the formation of the first Metropolitan Commission of Sewers, the Commission was six times superseded, and six new Commissions appointed, all with different powers, and differing widely as to the talent of the members of the successive reconstructions. The first Commission commenced very vigorously with Trial Works, and a new era was expected to dawn upon the scientific world by the labours of the experimentalists. Their successors, however, discarded the entire system of experimental and trial works, very much to the disgust of the would-be scientific reformers, who have lost no opportunity, ever since, of deploring the ignorance and incapacity of their successors in abandoning the experimental works and the theories said to be based upon them. The great difficulty with the Government of the day appeared to be to discover, by numerous trials, not the best mode of carrying out works, but the best mode of forming a governing body which could hold together sufficiently long to devise and execute some scheme that would allay the clamour, which was becoming louder and louder every day, on the subject of defective drainage in general, the pollution of the Thames in particular, and the occasional dread of the cholera, as well as the fatal results of several actual visitations.

The eight Commissions to whose government London in all its extent was distributed previously to the year 1847, could not, from their independent action, be expected to devise and execute any great scheme; neither could their successors, the six Commissions appointed in the space of nine years, during the limited period of their existence devise and carry out works of sufficient magnitude to meet the extensive and complex nature of the case.

The subject of the drainage of London is sufficiently complex in itself, as a mere scientific problem; but during the existence of the six successive Commissions, various projects for the utilization of the sewage of the metropolis, and also for a grand scheme of water-supply, were brought forward, and very much complicated and retarded the whole question. Bagshot Heath was to be the gathering ground for the supply of London with water, pure and of the softest description, and millions of money were to be saved in the article of soap alone. The subject also was, to a great extent, a political one, and necessarily so. Taxation without representation is an old bone of contention, and the members of the earlier Commissions were the mere nominees of Government. Local self-government was also up in arms against centralization, and consequently the successive Commissions were modifications and compromises with the view of harmonising antagonistic interests.

All these successive Commissions, even the most mischievous and crotchety of them, did something towards arriving at a good system. For several of the Commissions pointed in the right direction, and indicated, however faintly, what ought to be done; whilst others went sufficiently far wide of the mark to point out very distinctly what ought to be avoided; and this is no mean assistance in the endeavour to evolve a good practical system from a chaotic mass of ill-digested schemes, and in opposition to many conflicting interests.

The want of a general survey of London, with accurate levels, was felt during the existence of the earlier Metropolitan Commissions, and the Ordnance Department undertook to execute the work for a stipulated sum of money. An outline plan of London and suburban districts was soon produced, based upon a trigonometrical survey, engraved and published upon a large scale, and also upon several useful reduced scales. This survey has become the basis of all railway and other projects, whether public or private, which have been undertaken since the completion of the work. The levels are reduced to the mean sea-level at Liverpool, and when this datum is carried to London, it is eight feet six inches below the Trinity datum. Bench-marks are permanently recorded upon the walls of the most substantial and permanent buildings and other objects.

The Metropolitan Sewers Act of 1848 (11 & 12 Vict. c. 112), which first established one general Commission for the metropolis, limited the amount of rates,

which the Commissioners were empowered to levy, to one shilling in the pound; a subsequent Act reduced the amount to threepence in the pound, which was not sufficient to keep in efficient repair existing works, and altogether inadequate to meet the expense even of getting up extensive and elaborate schemes, much less to execute them.

The first Commission was superseded in 1849, and the second Commission issued. At this time the Thames had become full of sewage, and very offensive; the cholera was raging in the ill-drained districts of Bermondsey, and several other low-lying portions of the metropolis; and as several of the water-companies continued to take their supply from the Thames, abundant materials were furnished to the public press for an active and incessant agitation for remedies to meet such glaring and destructive evils. In the midst of these perplexities the Commissioners advertised for designs for the purification of the Thames, which virtually included the whole question of the drainage of the metropolis. In answer to this application one hundred and sixteen plans were sent to the Commission. The examination of so great a mass of projects, of various degrees of merit or demerit, was very much complicated, and the arrival at a satisfactory result was prevented by plans being prepared by two of the officers of the Commission. Both of these plans found zealous supporters, and the contest was carried on warmly, and resulted in little more than a war of words; whilst the public clamour for remedial measures waxing louder and louder, produced so great a pressure upon the Government that it was induced to displace this second Commission and to issue a third.

It would appear from the known ability and professional standing of the members of the third Commission, both as civil and military engineers, and as possessed of administrative abilities of the highest order, that they were well calculated, by accepting the appointment, to extricate the Government from the difficult position into which it had been placed by superseding the original local Commissions, and by being unable to organise a good workable general Commission. This Commission commenced its labours by arranging and classifying the immense mass of plans sent in to the previous Commission, but eventually arrived at the conclusion that none of these plans could be adopted for execution. This conclusion might be considered, from the nature of the circumstances, to be inevitable. The parties sending in the several projects were not in possession of sufficient reliable data to enable them to devise and thoroughly comprehend a plan of general drainage for the metropolis. To enter into anything like details on so extensive and complex a subject as the efficient and economical drainage of the metropolitan district, together with the purification of the River Thames, required a larger stock of local information of an accurate and specific character than could be collected by the unaided efforts of individuals, at least in the short time allowed, without undue expense and waste of time. It must also be borne in mind that at the period when the Commissioners advertised for plans, there was no authentic general plan of London in existence, with accurate levels reduced to a uniform datum, and consequently no sufficient basis existed upon which to build up a project. A compiled map on a small scale, with levels approximately correct, was furnished to those who intended to respond to the appeal of the Commission.

Many of the plans sent in were doubtless of a very inferior description, and several of the projectors appeared altogether to lose sight of the object sought to be attained. There were, however, many of the projects in which the plan finally adopted was more or less vividly foreshadowed, and no doubt furnished useful hints to the parties working out the matured plans which have been successfully carried out—whether the best possible under the circumstances, time alone can tell.

The Commission then appointed Mr. Frank Foster as their engineer, and instructed him to prepare a scheme for the main-drainage of the metropolis, placing at his disposal the pre-accumulated mass of information which lay before the Commission in the one hundred and sixteen plans sent in to their predecessors, and carefully classified, examined, and reported upon to the Commission by a scientific committee of its members. Mr. Foster was assisted by Messrs. Grant and Cresy in the preparation of his plan for the interception of the sewage of the district south of the Thames, and by Mr. Haywood in preparing a plan for a similar purpose for the districts on the north side of the Thames. Mr. Foster's plan of interception-sewers for the district south of the Thames was never completed, but his plan for the drainage of the district north of the Thames upon the principle of interception was completed in 1851.

When this Commission was ready to commence the construction of the new system for the drainage of the metropolis, the Parliament deprived it of the power of raising more money from the ratepayers than was necessary to keep existing works in repair, and the Commission consequently resigned.

In 1851 a fourth Commission was issued, and the Commissioners commenced the consideration of the plans prepared by Mr. Foster and his assistants; but, unfortunately, a member of the Commission proposed a rival scheme to that of Mr. Foster, and this caused a division among the Commissioners upon the merits of the two plans before them. Mr. Foster's health failed under the anxieties of his position—sufficiently irksome under ordinary circumstances, but increasingly so when he was opposed by a part of the Commission. He resigned his office and soon after died, and the Commission was superseded.

A fifth Commission was appointed in the latter end of 1852, and was met at the outset of its proceedings

by a scheme which was submitted to Parliament by a private company under the title of the "Great London Drainage." This company adopted the engineering project of a Mr. Morewood, who had been advocating the principle of interception from the year 1845. His principle was to have a deep sewer near the Thames on each side of it, and to carry off the whole of the sewage and rainfall to deodorising works in Greenwich and Plaistow Marshes, and there to pump the whole up to the surface, the heights being forty and fifty feet. No portion of the sewage or rainfall was to be carried off by gravitation. This system only professed to drain thirty-nine square miles on the south side of the Thames, and about thirty-one square miles on the north side.

The company expected to derive a considerable profit from the fertilising agents recovered from the sewage, which was to be precipitated at the deodorising works, and sold as dry manure. The company, however, did not rely altogether upon the anticipated profits to be derived from the sale of the dry manure, a three-per-cent. guarantee upon one million pounds, the proposed capital of the company, being introduced into the Bill. A great part of the Parliamentary Session of 1853 was occupied in the consideration of this scheme, which was supported by engineers and contractors, but ultimately rejected by a Committee of the House of Commons on the evidence of distinguished engineers. Much valuable time, however, was lost, as the operations of the Commission could not be carried on with confidence whilst a doubtful issue was impending.

In the year 1854 Mr. Bazalgette succeeded Mr. Foster as principal engineer to the Commission, and was instructed to prepare a system of intercepting sewers for the purpose of effecting the main-drainage of London. Mr. Haywood, the engineer of the city sewers, was associated with him in designing the portion of the work north of the Thames. When the plans for the drainage of the northern district were prepared, they were submitted to the late Mr. Robert Stephenson and Sir William Cubitt, who were consulting engineers to the Commission, and who devoted much time and attention to the consideration of the plans laid before them, and ultimately recommended their adoption.

At the moment, however, when the carefully-studied plans of the engineers appeared likely to be carried into execution, a new complication arose in consequence of proposals made to the Government by a gentleman of the name of Ward, whose plans received the sanction of the then Secretary of State for the Home Department. This plan involved the separation of the subsoil and surface-drainage of the metropolis, and a system of double drainage for each house.

This plan was of so sweeping a character that all the steps which had been hitherto taken to perfect plans for the drainage of the metropolis would become useless by the adoption of the proposed alterations, and the expense would be nearly doubled. It was, moreover, but a mere suggestion, and not a matured plan followed out to its ultimate results, and ought not to have been listened to.

The Commissioners totally disapproved of the proposed system of drainage thus attempted to be thrust upon them, and, finding that they were at issue with the Government upon the fundamental principles of the operations which they were expected to carry out, forthwith resigned their office.

A sixth Commission was appointed in the year 1855, and composed of members partly nominated by Government and partly chosen by election. This Commission invited new plans, and considered several of them, but did not arrive at any solution of the general question. It has also been surmised that many of the members of this Commission wasted much valuable time in making speeches. This Commission was superseded by the present Metropolitan Board of Works.

Nothing could be more palpably evident than that this rapid succession of so many Commissions was a blot upon the administrative powers of the executive government, upon the principles of the constitution, and upon the common sense and engineering talent of the country. The successive Commissions broke down from one or more of the following causes: Amateur engineering, combined with a mania for experimenting; internal divisions, caused by members of the Commissions having pet projects of their own; the want of funds to carry out extensive projects; undue Government influence; and an excess of oratory.

The necessity for some decisive steps being taken in devising and carrying out an improved system of drainage for the metropolis was becoming more and more urgent. The ravages of the cholera in the years 1831-2, 1848-9, and in 1853-4, were very great. In 1849 the deaths from cholera were 18,036, and in 1854 nearly 20,000; and whatever opinion may be entertained upon the nature of the malady, and the manner in which it is carried from one country or locality to another, nothing could be more evident than that imperfect drainage was a predisposing cause of the disease. The imperfectly-drained districts suffered very severely from the disease, and when these districts were properly drained they became quite free from it.

In January 1856, Sir Benjamin Hall's Metropolitan Local Management Act came into operation, which constituted the present Metropolitan Board of Works. Under this Act, the whole drainage area is divided into thirty-nine districts. The ratepayers of these districts elect from among themselves a prescribed number of representatives, who form a vestry or district board. These boards manage the drainage, paving, lighting, and other local improvements of their respective districts, and elect from their several bodies one or more members, in proportion to the population and the extent

of each district, to form the Metropolitan Board of Works, which consists of forty-five members, presided over by a chairman, who is elected by the board. The board has control over the main sewers, the Thames Embankment, new streets, and all metropolitan improvements, and frames bye-laws for the direction and control of the several district boards.

This Act concedes to the fullest extent the combination of the representative and the rating principle. The Metropolitan Board of Works can only raise the amount of rate fixed by Parliament, and the ratepayers elect the members of the general board, and also of the local boards, who are responsible to them for the manner in which the rates are expended. The minor operations of drainage, lighting, paving, cleansing, and all local improvements of an ordinary character, are executed by the local boards, and by officers appointed by these boards, thus extending local self-government almost to every ratepayer's door.

This Act also, in a very admirable manner, combines centralization with local self-government. The whole of the operations, which can only be treated as a combined system, are under the entire control of the central board and their respective officers; any other mode of treating the main-drainage would be an utter failure. The multifarious operations of the several districts, if concentrated into one central office, would be altogether unmanageable, whilst the central board has sufficient control over the district boards to ensure uniformity of action. The central board has to find outfalls for the whole drainage area—the several district boards find an outfall in the nearest intercepting sewer. Individual complaints can be more easily made, and more readily disposed of, in the respective districts where they occur, than by an appeal to the central board.

When the Metropolitan Board of Works was constituted, Mr. Bazalgette was appointed principal engineer to the board, and received instructions to prepare plans for the drainage of the metropolis. These plans, when completed, were approved of and adopted by the board. Unfortunately, however, another delay was inevitable: for, notwithstanding that the Government failed so often to form a Commission which did not contain the elements of destruction within itself, or which could hold together sufficiently long to devise and carry out a practical system of drainage for the metropolis, it still clung to some vestige of control over the newly-constituted board, as may be seen by the following veto-clause in the Bill:—"That before the Metropolitan Board of Works commence any sewers and works for preventing the sewage from passing into the River Thames as aforesaid, a plan, together with an estimate of the cost of carrying the same into execution, shall be submitted by such board to the Commissioners of Her Majesty's Works and Public Buildings; and no such plan shall be carried into effect until the same has been approved by such Commissioners."

The First Commissioner of Works, by virtue of the above clause in the Act constituting the Metropolitan Board of Works, refused his sanction to the plans submitted to him by the board, upon a technical point. His veto was resisted by the board, and the difficulty was ultimately removed. The First Commissioner, however, submitted the plans of the Board of Works to three scientific gentlemen as referees, as may be seen by the following extract from the First Commissioner's letter of the 31st December 1856, appointing and instructing the referees:—"The First Commissioner wishes also that you should not confine yourselves merely to the plans submitted by the Metropolitan Board of Works; he desires to have the fullest information you can afford him; and if you can devise any other scheme which may, in your opinion, be better calculated to carry out the object in view, he requests that you will in your report set forth that scheme, in order that he may lay it before the Metropolitan Board of Works for their consideration." The above extract shows that the whole question, upon its broadest basis, was again fairly opened, as there was no limit set to the investigations of the referees. There can be no doubt but the Act under which the Metropolitan Board of Works was constituted gave to the First Commissioner a veto upon the plans of the board; but it is not so clear that the Act gave him power to substitute a fresh scheme, to place before the Metropolitan Board of Works as a counter-project to that which had been propounded by the board, and submitted for the First Commissioner's approval.

The referees, armed with full powers to investigate the whole question, seemed to bestow very little labour upon an examination of the plans of the Board of Works submitted to them, but set vigorously to work to devise an entirely new project, extending much beyond the drainage area sanctioned by the Act.

The first step was to advertise for gratuitous aid from anyone disposed to supply plans or suggestions, in the following terms:—

"The plans for the main-drainage of the metropolis having been referred to Captain Douglas Galton, R.E., James Simpson, Esq., C.E., and Thomas E. Blackwell, Esq., C.E., notice is hereby given that all persons desirous of communicating with those gentlemen upon the subject may direct letters, plans, &c., to them at their office, No. 29 Great George Street, Westminster, on or before the 2·th February next. Dated 10th January, 1857." Directions followed as to scales, margins, &c.

Several hundred plans and suggestions were sent in to the referees in response to the above invitation—indeed, such a mass of ill-digested and irrelevant matter as was much more likely to confuse, than to enlighten and assist, the referees. The idea and means of utilising the sewage entered largely into almost every project.

The referees also had chemical investigations made by eminent chemists, upon "the influence of sewage upon

the river," the "actual agricultural value of London sewage," "which of the various modes for treating sewage by chemical agents would be the best," the "value of sewage for purposes of irrigation," the "manufacture of sewage in a sanitary point of view," and also "with regard to the several modes of deodorization, simply as such."

The chemical report sent to the referees is a very long and, no doubt, a very valuable one; a great portion of the report is, however, taken up with the apparently endless question of the utilization of sewage for the purpose of manure; and the conclusion arrived at is, "that the problem of profitably recovering the valuable constituents of sewage remains, up to the present moment, unsolved, and very faint indeed are the hopes that the progress of chemical discovery will supply the means of so doing."

The report of the referees to the First Commissioner is dated 31st July 1857. The referees disapprove of the outfalls proposed by the Board of Works in Erith Reach, and propose that the outfall on the north side of the Thames should be between Mucking Lighthouse and Thames Haven, in Sea Reach; and on the south side, at Higham Creek, in the Lower Hope.

The referees also state that the plan of the Metropolitan Board of Works does not provide for the removal of a sufficient quantity of sewage *from the* metropolitan districts, that the channels leading to the outfalls are not sufficiently large; and they propose to construct a channel on the north side, 39 feet broad and 16 feet 6 inches deep, and on the south side 37 feet broad and 16 feet deep, with a fall of 6 inches per mile, and a velocity of 2 feet 6 inches per second. But the above velocity could not be maintained unless the channels are kept nearly full, and when this cannot be done by natural means, it is proposed to be effected artificially by a supply of water from the Thames at high tide, in some cases directly, but principally by means of storage reservoirs.

The referees also extended the drainage area beyond the metropolitan district 130 square miles on the north, along the valley of the River Lea, and 86 square miles on the south, along the valleys of the Ravensbourne, the Wandle, and Baveley Brook. It is difficult to account for this extension of the drainage area, as, upon the same principle, there can be no valid reason given why the whole valley of the Thames, with its numerous tributaries, should not be treated as one drainage area up to its source. The referees also propose not to consider the River Thames as naturally dividing the drainage area into two distinct portions, but propose to transfer the sewage from the western low-lying districts on the north to the south side, by a tunnel under the bed of the river at Battersea, and to raise it by pumping into a sewer on a higher level. Among the many hundred projects which had been submitted to the several commissioners, and to the Government referees, there was an almost unanimous opinion that the River Thames divided the metropolitan drainage area into two separate and distinct systems, requiring separate and distinct treatment, and separate outfalls.

The schemes of the referees, however magnificent and expensive, can only be considered as crude suggestions, inasmuch as that they abandoned position after position, and proposed fresh plans and modifications whenever their plans were brought to a scientific test.

On the 24th November 1857, the Metropolitan Board of Works appointed Messrs. Bidder, Hawksley, and Bazalgette to report to the Board the best means of carrying out the main drainage of the metropolis. To these gentlemen was submitted the report of the Board, which had been sent to the First Commissioner, and by him referred to the referees, together with the voluminous report of the referees. These gentlemen set vigorously to work, and sent their report to the Board of Works on the 6th April 1858. Their first operations were generally confined to an examination of the report of the referees, and frequently to such a dissection of the report as induced the referees to alter and modify their plans three several times, not in mere details, but in essential and fundamental principles. The first plan proposed by the Government referees involves, among other propositions, the following important points:—

1st. A wider extension of the metropolitan drainage area.

2nd. The construction of main sewers capable of discharging greatly increased volumes of sewage and rainfall.

3rd. The construction of reservoirs and channels on both sides of the Thames, for the purpose of flushing and diluting the contents of the proposed outfall sewers.

4th. Outfall sewers extending for about 24 and 23 miles on the north and south sides of the river respectively.

5th. The discharge of the sewage into the Thames at two points below Gravesend.

6th. The transfer of the western division of the northern low-level sewage from the north side to the south side, by means of a tunnel under the Thames at Battersea.

In the first report by the referees, it was proposed to have two great outfall sewers, partially uncovered and partially tidal—the sewage to be diluted by six or seven times its own bulk of water. This plan was modified by subsequent plans.

The great difficulty which the adoption of remote outfalls necessarily creates, when the fall is very small, is, that velocity of current must be obtained by increasing the quantity of the fluid mass in order to increase the hydraulic mean depth; and this hydraulic mean depth must be kept up to a uniform regime by artificial

means, as the flow of sewage is not uniform, and, when combined with rainfall, is still more irregular as to quantity. The referees proposed to maintain this constant hydraulic mean depth by taking in water from the Thames at high tide, at the head of their outfall sewers, and also by a supply of water from reservoirs, which were to be constructed on each side of the river, at points which were from time to time altered in the several plans proposed by the referees. These remote outfalls also encountered many and great difficulties in passing rivers and streams by the outfall channels. In some cases it was proposed to pass in syphons, on the north side, for example, under the River Lea, the Three Mill Stream, and the Channelsea River (a branch of the Lea), and also under the River Roding at Barking. On the south side of the river there were also many difficulties encountered, the mode of overcoming which does not appear to have been maturely considered. The Darent was to be crossed under by a syphon, but in a subsequent plan it was proposed to be carried over the sewer in an iron aqueduct.

The referees appeared to have anticipated some difficulties in the working of syphons, or, as they called them, "depressions," under the rivers and streams crossed by the outfall channels; they proposed to lower the sewers, so "as to enable the several streams to be passed without any depression of the bottoms." In consequence of this alteration of depth, in order to regulate the velocity, the width was to be respectively 25 and 22 feet at the head, gradually increasing to no less than 60 feet and 57 feet at the outfalls. As these large sewers could never be supplied with sufficient drainage-water at their upper ends, it was proposed to make them tidal through their whole length, the tide entering from their lower ends. Under the first plan, the outfall channels were to be open for the greater portion of their length, but in the second plan they were to be covered, with the exception of portions near their lower ends. Another important alteration was, that the sewers at their upper ends were to be depressed 9 feet 6 inches and 10 feet respectively, and at the outfalls 3 feet and 3 feet 6 inches respectively; they were also to be brought to a uniform fall of 6 inches to a mile.

The third plan of the referees altered the outfall channels in almost every particular, as to direction, size, and levels. On the north side the outfall sewer commenced near the River Lea, 24 feet 6 inches below Trinity high-water mark, and for the first four miles of its course the sewer would have an average internal width of 22 feet, and an average depth of excavation of 34 feet 6 inches. The internal width of the channel would be gradually increasing to 35 feet, with a depth of excavation of 50 feet, and terminating in an open channel about 32 feet deep, and an average width of 118 feet at top-water. The level of the bottom of the channel at the outfall is 17 feet below average low-water mark at Sea Reach.

On the south side of the river the outfall channel commences at the River Ravensbourne, 23 feet 6 inches below Trinity high-water mark. The first three miles of its course would pass partly through a densely-populated locality, and partly through Greenwich Park, at an average depth of excavation of 40 feet 6 inches. The tunnels on this line are—at Woolwich, 1½ mile long; at Erith, two tunnels, 150 and 630 yards long respectively; and at Gravesend, passing under the heart of the town, 2,300 yards long, with an internal width of 30 feet 6 inches, and a height in the clear of 34 feet 6 inches. After the Gravesend tunnel the sewer will pass under the Thames and Medway Canal. The open portion of the channel will be two miles and 1,500 yards long, 32 feet deep, with an average width of 108 feet at top-water. The bottom of the proposed outfall at Higham Creek will be about 5½ feet below the average low-water mark at Sea Reach. In this outfall sewer there are very deep cuttings between the tunnels, producing great quantities of surplus earth, which must be disposed of.

This very cursory glance at the magnitude of the works proposed in the execution of these outfall sewers must convince any one that the engineering difficulties are of no ordinary description. The sewers in a large portion of their course will pass through silt gravel, quicksand, and chalk, charged with an almost inexhaustible quantity of water, being placed at a level of 4 or 5 feet below mean low-water mark. As the very deep excavations are proposed to be taken out vertically, and of the exact width for the reception of the brickwork and concrete, there must be at least 40 miles of timbered channels; and considering the width of these channels, this timber strutting would be a matter of great difficulty, danger, and expense. The pumping of so much water as may reasonably be anticipated from an average depth of 30 or 35 feet, would prove to be an operation of considerable magnitude and great expense.

In such treacherous soil it is evident that the brickwork constructed in open cuttings, and subsequently filled in, would require to be of the most substantial character, and there would be no portions of the work where an invert could be dispensed with.

The tunnels being of greater dimensions than the usual railway tunnels, would require to be very substantially built, and of the best material, as the sewage would doubtless have a deleterious effect upon the lining of the channels through which it flowed. The thickness of the brickwork estimated by the referees is very much less than what is in general employed in railway tunnels, being only 18 inches in the lower half, and 22½ inches in the upper half. There is concrete on the outside of the brickwork, averaging about the thickness of the brickwork, which may be very useful as a packing behind the walls when the timbering is being removed, but can add very little to the strength of the brick casing. The referees appear to have had some mis-

givings upon the subject of strength, and they have inserted "longitudinal ribs," apparently for the purpose of strengthening the brick lining of the tunnels, but it is difficult to comprehend how ribs placed longitudinally can add to the strength of the tunnel. Had the ribs been placed as circular rings, not very distant from each other, they would have acted as counter-forts act in strengthening revetment walls.

In the third and most improved plan of the referees, there appear to be great difficulties experienced in devising the means of crossing the watercourses of the district. The syphon system appears in this plan to be abandoned, and the levels of the sewers being altered, several of the watercourses are now proposed to be passed through the course of the sewer by large iron troughs; and, in order to maintain equal sectional area throughout the channel, to insure uniformity of flow, the sewer is widened out at the points where the troughs are placed. On the north side of the Thames, the Rivers Channelsea and Roding, the Dagenham and Rainham Brooks, and the Mardyke at Purfleet, are to be passed through the sewer. There are some streams also said to be taken into the sewer, but which the levels will not permit to be so treated.

On the south side of the Thames the River Darent and the Thames and Medway Canal are to be passed over the sewer in iron troughs; and the Springhead stream, near Northfleet, is to be passed through the sewer in a pipe. From Woolwich to Erith, and from the River Darent to Greenhithe, no provision is made for passing the upland waters across the sewer. This is a very serious omission, as the marsh-lands, being cut off from the upland waters, would be materially injured thereby.

Tide-filled reservoirs on both sides of the Thames were a peculiarity of the several plans and modifications of the referees. By the first plan the reservoirs were to be placed in Plaistow Marshes on the north side of the Thames, and in the Ravensbourne Valley on the south side, but in both these situations there were insurmountable difficulties to contend against; and the second plan placed the northern reservoir at Channelsea Island, and the southern in the Greenwich Marshes; the third plan placed the reservoir on the south side near Deptford Creek, on the north side of Greenwich railway station.

In some positions of the reservoirs the levels were so arranged that considerable engine power would be necessary to pump the water from the reservoirs into the outfall channels. Under the most favourable aspect of the case the reservoir system could only be a failure, the difficulty being that of regulating the levels, so that the reservoir could be filled sufficiently from the Thames at spring and neap tides, the supplying of water from the reservoirs to the outlet channels in such quantities as to dilute the sewage to such an extent as the referees considered essential, and the supplying of scouring water so regular as to keep up a uniform flow in the channels. The water from the Thames would be so turbid that the reservoirs would be settling-ponds for the accumulation of mud, which could only be removed by dredging and at great expense. There can hardly be a doubt that the idea of collecting, diluting, and scouring water in reservoirs, so tenaciously adhered to by the referees in all their plans, materially embarrassed and vitiated their several plans of outfall sewers. The reservoirs would be very costly in themselves, expensive to keep clear of mud, and not only useless, but would materially increase the evils they were designed to remedy.

In some of the projects of the referees, the outfall channels are said to be tide-locked, and in other cases to be tidal throughout, the tide entering from the lower ends. When tide-locked, there would be a considerable period of time during each tide when the sewage in the outfall channels would be in a perfectly quiescent state, and consequently the weighty matters held in suspension would be deposited; and when the tidal flow admitted into the channels at the points of outfall would meet, and neutralise the downward flow of sewage, there would also be such a quiescence as would cause a considerable deposit. But a still greater deposit would result from the circumstance that the bottom of the proposed outfall sewer on the south side of the Thames will be about 15½ feet below average low-water mark at Sea Reach, and on the north side about 17 feet below average low-water mark at the same point. It must be evident, therefore, that the sewage in the portions of the outfall channels placed below the mean of low-tide level must remain in a perfectly quiescent state, and become perpetually tide-locked, and, consequently, elongated cesspools to all intents and purposes. In the first plan proposed by the referees, the greater portion of the outfall sewers were open, but in the second and third plans there were only a few miles at their lower ends open. The proposal to pass rivers through the outfall sewers is probably a novelty in engineering science.

After a careful examination of the several plans proposed by the referees, the engineers appointed by the Metropolitan Board of Works came to the following conclusions:—"That the plan recommended by the Government referees is needlessly large, excessively costly, and, as a work of construction, all but impracticable." Also, "that the probable cost of the smallest project will be upwards of 9,000,000*l*."

Experiments were made in the river with floats by all parties who were investigating the points of outfall most proper to be adopted in the disposal of the sewage of the metropolitan district. But as far as mere sewage is concerned, the float experiments are most fallacious, there being no analogy between a float occupying a given position in the stream, and a mass of sewage becoming decomposed and incorporated with a great

body of water so soon as it enters the river. The float experiment may, however, give some approximate data as to the period of tide most proper for the discharge of sewage into the river.

It is said to be demonstrated by a series of float experiments, that "The delivery of the sewage at high-water into the river at any point is equivalent to its discharge at low-water at a point twelve miles lower down the river; therefore the construction of twelve miles of sewer is saved by discharging the sewage at high instead of low-water."

The general principle upon which all drainage schemes must be based is, first, the determination of the drainage area; secondly, the outfall, or the point where the sewage can be most conveniently disposed of; and thirdly, the best means of collecting and conveying the sewage to the outfall. In applying these general principles to any particular locality, several other points of primary importance will present themselves. Applying these principles to London and the suburban districts, it is very obvious that the River Thames divides the drainage area into two distinct portions; and being dissimilar as to levels and other peculiarities, each district must have a distinct treatment. The northern and southern limits of these drainage areas are obviously the watershed on each side of the valley through which the river flows.

The plan proposed by the Metropolitan Board of Works, condemned by the Government referees in almost every point, but approved, with slight modifications, by the engineers to whom the question of metropolitan drainage had subsequently been referred, appears to be, in its broad principles, to accept the drainage area which nature has pointed out; to allow no sewage to pass into the Thames from the drainage area, but to dispose of it at points of outfall on the river most remote from inhabited districts, but not so distant as to deprive the outfall channels of an efficient scouring descent. The sewage in the low-lying districts north and south of the Thames could not be disposed of but by raising it to a higher level by artificial means; and this, under any circumstances, being an expensive process, the principle of not permitting any sewage from the upland districts to flow into the low-lying sewers was carried out to the fullest possible extent, by a system of intercepting sewers carrying off their contents by gravitation to the proposed outfalls.

In the almost interminable discussions upon the drainage question, the purification of the River Thames, the positions of the outfalls, and the nature and capacity of the outfall channels, appear to have engrossed much more attention than the still more important consideration of rendering clean and wholesome the dwellings of the immense population of the metropolis, and more especially the densely-populated and ill-drained districts inhabited by the poorer classes, who can seldom ever breathe purer air than the poisoned atmosphere of their own lanes and alleys.

There can be no doubt that the difficulties of the drainage of the metropolis were greatly increased by the previously existing drainage having been constructed upon erroneous principles, under divided and conflicting authorities.

The plan of the Metropolitan Board of Works, which was finally approved, and which has been carried out (see Plate No. 1), consists, on the north side of the Thames, of two principal lines of sewers, which discharge their contents by gravitation into the river at Barking Creek at high tide. The most northern of these sewers commences to the south of Highgate, by a junction with the Fleet Sewer, passes along Gordon House Lane, across the Highgate Road, and under the Great Northern Railway and the New River to High Street, Stoke Newington; thence proceeding eastward to the valley of the Hackney Brook, and crossing the Victoria Park to Old Ford. This sewer is about 7 miles long, and drains an area of about 10 square miles. The Mid-Level sewer commences near the Harrow Road at Kensal Green, passes under the Paddington Canal into the Uxbridge Road, along Oxford Street, Hart Street, Liverpool Street, across Clerkenwell Green, along Old Street, and nearly direct to the south-west corner of Victoria Park, where it passes under the Regent's Canal, to a junction with the High-Level sewer at Old Ford. The length of this sewer is about 9½ miles, and the area intercepted is 17½ square miles. In order to carry off the greatest possible amount of sewage by gravitation, there is also an intercepting branch-sewer carried along Piccadilly, through Leicester Square, Lincoln's Inn Fields, and joins the Middle-Level sewer at King's Road, Gray's Inn Road, the length of which is about two miles. The fall in the High-Level sewer is considerable, ranging, at the upper end, from 1 in 71 to 1 in 376, and from 4 to 5 feet per mile at the lower end.

The Northern Outfall sewer commences at Old Ford, where it receives the contents of the High and the Middle-Level sewers, and extends to the point of discharge into the river at Barking Creek. This outfall sewer is a work of peculiar construction, as it is raised considerably above the surrounding ground, upon an embankment, and a portion of the lower end upon brick arches. This mode of construction has been adopted for the purpose of discharging the sewage into the river at the point of outfall at high tide; it also gives great facilities for crossing over rivers, streets, public roads, and railways, in its course. The first portion consists of two parallel culverts, as far as Abbey Mills; and as the contents of the Low-Level sewer are raised at this point into the Outfall Sewer, the remaining portion of it consists of three parallel culverts. The whole of this outfall channel has a fall of 2 feet per mile, and the invert of the sewer at its outlet is about

18 inches below high-water mark. At the outfall there is a reservoir (see Plate No. 13) covering 9½ acres, and divided into four compartments by partition-walls. The engineers to whom the plans of the Board were referred, recommended that "the Northern Outfall sewer be constructed in brickwork, and not in iron as designed, and that a carriage-road of 40 feet be formed over it."

The Low-Level intercepting sewer on the north side of the Thames was originally intended to pass along the Strand, Fleet Street, and to the south of St. Paul's. This direction of the sewer was very much objected to, and if carried out would have been a very inferior plan to that which is being executed in the northern Thames Embankment. The question of the embanking of the Thames was at that time very much agitated, and in the report of the engineers, to whom the plans of the Board of Works were referred, an earnest conviction is expressed that "the Middle and High-Level sewers on the north side should be first proceeded with, not only for the more speedy relief of the low-lying districts from floods, but also to afford time for a determination to be come to with respect to the suggested formation of a Thames Embankment in connection with the construction of the northern Low-Level sewer."

So soon as an Act was obtained for embanking the Thames, it was necessary to reconsider the whole subject of the low-level drainage on the north side of the river.

The Low-Level intercepting sewer, properly so called, commences at the Grosvenor Canal, Pimlico, and passes under Lupus Street and Bessborough Street, to the bank of the river near Vauxhall Bridge; thence along the bank of the river, Millbank Street, passing through Old and New Palace Yard to the sewer in the Thames Embankment at Westminster Bridge, and continues in the embankment as far as Blackfriars Bridge; thence it will pass under a portion of the new street to the Mansion House, and thence by tunnelling to Tower Hill. From Tower Hill the sewer is carried by tunnelling under Mint Street, Cable Street, Commercial Road, Limehouse Cut, Bow Common, and the River Lea, to the pumping-station at Abbey Mills, where its contents are raised 36 feet by steam-power into the outfall channels before described.

There are two branches connected with the lower end of this sewer, one from Homerton, and the other from the Isle of Dogs, a district where the extensive river-frontage is becoming the site of numerous factories and works, and is largely populated by artisans and workmen. The length of the main line is 8¼ miles, and its branches are about 4 miles in length; its inclination ranges from 2 to 3 feet per mile, and it is provided with storm-overflows into the river. The Low-Level sewer drains an area of 11 square miles, and is also the outlet for the drainage of the western suburb of London, comprising an area of about 14½ square miles, and lying so low that its sewage has to be lifted a height of 17½ feet into the upper end of the Low-Level sewer. This western drainage area includes Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton.

The drainage of the south side of the Thames required a different treatment from that applied to the north side. On the south side of the river there is an extensive low-lying district, thickly populated, and subject to be flooded, not only from very high tides in the river, but from the upland districts during excessive rains. It was necessary, therefore, in designing the intercepting sewers for this district, to give them sufficient capacity to carry off the storm rainfall, and not permit it to fall into the low-lying grounds. It was also desirable to dispose of this storm rainfall as soon as possible, and not to carry it to the outfall, as no portion of the sewage on the south side of the river can be sent into the Thames at high tide by gravitation.

The southern main line of intercepting sewers commences at Clapham, and passes through Brixton, Camberwell, Peckham Rye, New Cross, to Deptford Creek. The Efra Branch commences at Dulwich (from which issue two branches, one to the Crystal Palace, and the other to Lower Norwood), passes through East Dulwich and Peckham Rye, where it runs parallel to the main line to Deptford Creek. These sewers together drain about 20 square miles, and the storm-waters collected from this area are disposed of by an overfall into Deptford Creek; whilst the sewage, together with the ordinary rainfall, is pumped into the outfall channel, which conveys them by gravitation to the outfall.

The Low-Level sewer on the south side of the Thames commences at Putney, passes to the south of Battersea Park, through Lambeth and Walworth, to the Old Kent Road, along which it proceeds to Deptford Creek. This sewer, together with the Bermondsey branch, drains Putney, Battersea, Nine Elms, Lambeth, Newington, Southwark, Bermondsey, Rotherhithe, and Deptford, comprising an area of 20 square miles; its length is about 10 miles, and the length of the Bermondsey branch about 2 miles. The fall of the main sewer is from 4 to 2 feet per mile, and the fall of the branch about 4½ feet per mile, and the contents of both main line and branch are raised to a height of 18 feet into the outfall channel.

The Southern Outfall sewer commences at Deptford Creek, where it receives the sewage from the High-Level sewer by gravitation, and that which is pumped into it from the Low-Level sewer, and passes through Greenwich and Woolwich to Crossness Point, in Erith Marshes. This outfall channel is 7¾ miles long; it is 11 feet 6 inches in diameter, and has a fall of 2 feet per mile. This sewer has been constructed at a depth of about 16 feet below the surface of the ground, except the

portion through Woolwich, where the depth varies from 45 to 75 feet. The soil in which it is constructed is gravel, sand, and chalk, with great quantities of water in passing through the Plumstead and Erith Marshes.

The whole of the sewage of the south side of the Thames is raised at Crossness to a height varying from 10 to 30 feet into reservoirs, from which it is discharged during the first two hours after the commencement of the ebb tide. The reservoir (see Plate No. 19), which is covered, is 6½ acres in extent.

In designing a system of intercepting sewers, the capacity for receiving and carrying off sewage and other matters must vary according to the duty each portion has to perform, and generally have a gradually increasing rise from the head of the sewer to the outfall. In adapting the size of the sewer to the different localities through which it passes, several circumstances must be taken into consideration. Some of the necessary data may be accurately ascertained, and others, by varying degrees of approximation; the fall in the sewer may be accurately ascertained; the existing quantity of sewage to be carried off may be ascertained with sufficient accuracy by numerous gaugings, and the prospective increase in the quantity from an increase of population may be estimated with tolerable certainty; but the most uncertain element to be dealt with is the rainfall. A material distinction should be made between the quantity of rain to be carried off by the sewers and the actual rainfall on drainage area. The latter is the gross quantity which reaches the earth, and the former is only the residual after absorption, evaporation, and other causes of diminution. The variations of atmospheric phenomena are far too great to admit of any philosophical proportion to be established between the rainfall and the sewage flow. In the system carried out by the Board of Works, the only real safe plan has been adopted—that of providing overflows along the natural drainage valleys, and allowing the excessive rains, which only occur for a few days in the year, to flow off. Should there be no points of overflow provided, the sewers must be made to carry off the most extreme rainfall on record. In the storm of 1st August 1846, the rainfall in 2 hours and 20 minutes was 3·3 inches.

The plan of internal drainage for the metropolitan districts proposed by the Government referees, differs in many essential points from the plan of the Board of Works, which is now nearly completed. The two plans for the High-Level sewer on the north of the Thames did not materially differ from each other; that of the Board of Works was, however, preferable, as it went further to the west, and intercepted the two higher branches of the Fleet sewer, and the waters descending from the high grounds of Hampstead and Highgate. From the northern High-Level sewer to the Thames, the plan of the referees differs very essentially from that of the Board of Works; they disapprove of the Middle and Low-Level sewers of the Board of Works, and propose a main intercepting sewer to drain eastward to Abbey Mills, and there to be discharged by gravitation into the Northern Outfall channel. The Low-Level sewage is disposed of by the referees, by collecting it from the Hackney Marsh and the eastern district near the Thames, and raising it by artificial means into the Northern Outfall channel, "whilst the Low-Level sewage west of Somerset House shall be carried back to nearly opposite Battersea, and then across the river, there to be raised by artificial means into a southern High-Level sewer."

On the south side of the Thames the Government referees propose a High and Low-Level sewer, and to concentrate the sewage at Deptford; but they propose to bring the Putney and Wandsworth waters to Battersea, and there lift them with a portion of the Lambeth sewage into the High-Level sewer. The referees also propose to commence their High-Level sewer at Richmond, to cross the valley of the Wandle by an elevated aqueduct of one-fourth of a mile in length, and then to take the general direction of the High-Level sewer of the Board of Works to Deptford Creek, where the outfall channel commences.

DESCRIPTION OF THE PERMANENT WORKS OF THE METROPOLIS MAIN DRAINAGE, EXECUTED UNDER THE DIRECTION OF THE METROPOLITAN BOARD OF WORKS.

NORTH SIDE OF THE THAMES.

THE Thames naturally divides the drainage area into two distinct systems. On the north side there are three main intercepting sewers, called the High-Level, the Mid-Level, and the Low-Level sewers; in addition to these there are some collateral branches. The High-Level sewer commences by a junction with the Fleet sewer at the foot of Hampstead Hill, passes through Stoke Newington and Hackney, through Victoria Park, under Sir George Ducket's Canal, and forms a junction with the Mid-Level sewer about 200 yards after passing the canal. This sewer, being so near the northern

boundary of the drainage area, has more of the character of a drainage sewer than of an intercepting sewer, and its principal utility appears to be to take up the open Fleet and Hackney Brook sewers which have since been filled up and abandoned. This sewer is about 7 miles long, and drains an area of about 10 square miles; its form is mostly circular, and varies in size from 4 feet in diameter to 9 feet 6 inches by 12 feet. In the higher portions, the fall is rapid, being from 1 in 71 to 1 in 376, and at the lower end is from 4 to 5 feet per mile. Unlike the other intercepting sewers, which were only formed to take a portion of the rainfall, this sewer has been constructed of such dimensions as to be capable of carrying off the largest and most sudden falls of rain.

This sewer is constructed of good sound stock brick, and varies in thickness from 9 inches to 2 feet 3 inches. In order to withstand the scour resulting from the rapid fall, the invert is lined with Staffordshire blue bricks. Between Hampstead and Maiden Lane there is a tunnel about half a mile long, but presenting no difficult engineering work. Great care was necessary in tunnelling under the New River, where its channel is on an embankment, and also under the Great Northern Railway, where the embankment is 30 feet high, the sewer being 7 feet 6 inches in diameter, with brickwork only 14 inches in thickness.

It is of great importance to know that much property was successfully tunnelled under at Hackney; and one house was undermined and placed upon iron girders, and the sewer, 9 feet 3 inches in diameter, carried through the cellar without further injury to the house.

The only engineering work of any importance on this portion of the Metropolitan Drainage Works occurs in passing the sewer close under the bottom of Sir George Ducket's Canal, the distance between the soffit of the arch in the sewer and the water in the canal being only 24 inches. The division between the canal and the sewer is formed of iron girders and plates, with a thin coating of puddle, and no leakage has as yet taken place from the canal into the sewer.

As all the sewage which finds its way into the *Low*-Level sewer must be pumped up at very considerable expense, it is a matter of great importance that all sewage from the *upland* districts shall be intercepted or arrested in its progress downwards, and carried off by gravitation to the outfall at Barking Creek, on the bank of the Thames.

The Mid-Level sewer commences by a junction with the Counter's Creek sewer at the south side of the Great Western Railway, passes into the Uxbridge Road near Notting Hill, along Oxford Street and Hart Street, over the Fleet sewer, and thence over the Metropolitan Railway by a wrought-iron aqueduct 150 feet span and weighing 240 tons. This latter is rather an interesting work both as to the design and mode of execution. It consists of a double line of sewers, supported by boiler-plate girders, and only 2½ inches above the under side of the aqueduct, the sewers being supported upon the lower flanches of the girders. In order that the traffic of the railway should be carried on simultaneously with the construction of the sewers and the girders by which they are supported, a stage of great strength was carefully constructed about 5 feet higher than the intended level of the invert of the sewer, and upon this stage the whole structure was built of its entire length, and subsequently lowered into its permanent position by hydraulic rams.

After passing over the Metropolitan Railway, the sewer crosses Clerkenwell Green; thence it passes by Old Street Road to High Street, Shoreditch, along Church Street, Bethnal Green Road, and Green Street, under the Regent's Canal close to the south-west angle of Victoria Park, and joins the High-Level sewer at the Penstock Chamber, Old Ford. The length of this main line sewer is about 9½ miles, about 4 miles of which were constructed by tunnelling under the streets at depths varying from 20 to 60 feet. The area drained by this sewer is 17½ square miles in extent, and densely covered with inhabitants. The fall of this sewer is gradually reduced from 17½ feet per mile at the upper end to 2 feet per mile at the lower end.

In order to intercept as much of the sewage as possible from the Low-Level district, a branch sewer is carried along Piccadilly, passing through Leicester Square and Lincoln's Inn Fields, to the main line at King's Road, Gray's Inn Road. This branch is about 2 miles long; it is 4 feet by 2 feet 8 inches, and has a fall of 4 feet per mile. There are a few other minor branches and feeders connected with this Mid-Level interception. The whole of the Piccadilly branch was constructed by tunnelling.

In designing a system of drainage, it is a matter of very great importance to form correct principles upon the subject of the disposal of the rainfall over the whole drainage area. Tables of rainfall for several consecutive years ought to be obtained and acted upon, and no dependence should be placed upon observations extending over a limited period of time only. It would be a very great waste of money to construct the sewers of sufficient capacity to carry off the rainfall of extraordinary floods which only occur at very distant intervals, and it would also be a fallacy to receive the whole of the rainfall into the sewers upon the supposition of diluting the sewage, as the supply is so intermittent as to become comparatively useless for that purpose, and the extra size given to the sewers would retard the flow of the sewage when there was no addition to its mass by the rainfall.

There is no doubt that a large proportion of the rainfall is disposed of by absorption into the ground, and by evaporation; and the circumstances of atmospheric phenomena, and the ever-varying local pecu-

liarities which determine the proportions of each, are so various that nothing but approximate rules can be arrived at as to the quantity of rainfall likely to find its way into the sewers. The intercepting sewer must gradually increase in internal capacity as its course progresses towards the outfall, and this increase obviously depends upon the accessions of sewage, which gradually accumulate along the course of the sewer from the number and size of the tributaries falling into it. Much has also been said about the shape of sewers, which has not any practical bearing upon the subject of drainage, as the advantage of shape depends upon the quantity of sewage flowing through the sewer, and as this quantity is very fluctuating. To meet the theoretical requirements of the case, the shape ought constantly to vary with the quantities of sewage flowing through the sewer, and as this is obviously impossible, that shape of sewer which will meet the most general conditions of the case should be adopted. The circle is a good shape when it runs half full.

When an intercepting sewer passes over any of the natural drainage valley lines of the country, and sufficiently near the surface for that purpose, storm overflows should invariably be provided for the disposal of any rapid and excessive rainfall. Some of these are formed in connection with the Mid and Low-Level sewers.

From the junction of the High-Level sewers at the Penstock Chamber at Old Ford, an outfall sewer is constructed in nearly a direct line to Barking Creek, on the bank of the Thames. This is a work of peculiar construction, as the sewers are placed on the top of an embankment raised considerably above the surrounding grounds. This outfall sewer simply passes the sewage collected by the High-Level sewers, and that raised at Abbey Mills, from the Low-Level sewer to the outfall; and its peculiar structure, although very expensive, has some important compensating advantages in being so raised as to pass over roads, streets, railways, &c. The first portion of this work consists of two culverts placed side by side, 9 feet by 9 feet, with upright sides, semicircular crowns, and segmental inverts; and when the contents of the Low-Level sewer are raised at Abbey Mills, another sewer of the above dimensions is added. The embankment upon which these sewers are constructed is formed of concrete, carried down to a considerable depth through peat and soft alluvial soil to the gravel, and also carried up as an abutment to the sewers at each side, with a slope of 1 to 1. The whole structure is then covered with earth, the side slopes being $1\frac{1}{2}$ to 1, and the foot of the slopes being fenced in by a quickset hedge and ditch. The finished structure assumes the appearance of a simple railway embankment.

For about $1\frac{1}{2}$ miles of the lower end of this work a different mode of construction was adopted. The depth of the soft alluvial soil which had to be removed to form the concrete base of the works, became so great that it was found to be more economical to dig cross trenches, 6 feet 6 inches wide, down to the gravel, at every 21 feet. These trenches were filled in with concrete, and upon these, as piers, a series of brick arches was constructed, upon which the three parallel sewers were formed.

The works of the whole of the outfall sewers are of sufficient strength to admit of a railway or roadway to be placed on the top of the finished work at any future time, the top being 40 feet wide, and in some cases 25 feet above the level of the marshes.

The difficulty of designing this work arose from the circumstance that the fall of the sewer was reduced to 2 feet per mile, which could not be diminished, and therefore all public thoroughfares had to bend to this necessity. The first portion of the sewer passes under the North London Railway, which was supported by girders; under Wick Lane, which had to be raised 18 feet; and over the River Lea by a wrought-iron aqueduct, consisting of two wrought-iron culverts 57 feet span, and of the same section as the brick sewers. Between the River Lea and Stratford Road there are four streams crossed by tubes of similar section, but with spans from 18 to 45 feet. The sewers pass close under the rails of the Eastern Counties Railway through an embankment, and the work was completed without causing any interruption to the traffic on the railway. In crossing the Stratford Road, it was necessary to raise the latter 10 feet upon a viaduct, with an inclination of 1 in 50, and also considerably to modify the sewer, to prevent a still greater rise. The sewage was carried under the road by four culverts, each 6 feet high and 7 feet 3 inches wide. Having cleared the road, two culverts are adopted as before, and pass over Abbey Mill Lane by two wrought-iron tubes. Some distance farther on, the Abbey Mills pumping station is reached. At this point, the sewage from the Low-Level sewer is raised 36 feet by mechanical power, and to meet this augmentation of quantity, an additional culvert is added to the outlet channel. Gates and overflow weirs are formed between these culverts, by which means the sewage can be turned into either or all of them at will. Just beyond the pumping station, the three parallel sewers pass over Channelsea River and Abbey Creek, by cast-iron culverts, supported by four wrought-iron plate girders of two spans of 40 feet each. The sewers are then carried over Marsh Lane, the North Woolwich, and the Bow and Barking Railways, as well as several other roads, streets, and lanes of minor importance, in its course to the outfall at Barking Creek; the invert of the system of sewers being about 18 inches below high-water mark at the outlet.

The Low-Level sewer proper commences at the Grosvenor Canal, Pimlico. It intercepts and carries off

the sewage from a low-lying area containing about 11 square miles, and is also the main outlet for the drainage of a district containing about 14½ square miles, forming the western suburb of London, lying so low that its sewage has to be raised 17½ feet into the upper end of the Low-Level sewer. From the Grosvenor Canal the Low-Level sewer passes under Lupus Street, Bessborough Street, to the bank of the river at Vauxhall Bridge. It then continues along the bank of the river, and passes through Old and New Palace Yards to Westminster Bridge. From Westminster to Blackfriars Bridge the sewer is formed in the Thames embankment; and from the embankment it will pass under the proposed new road to the Mansion House, and along the line of the Inner Circle Railway to Tower Hill. From Tower Hill the line is carried by tunnelling under Mint Street, Cable Street, Back Road, Commercial Road, under the Limehouse Cut, Bow Common, and the River Lea, to the pumping station at Abbey Mills.

The Western District comprises Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton, and is drained by a main-line sewer and two branches falling into it. The main-line sewer commences at Chiswick Mall, passing near to the river along the Fulham Road and Walham Green, and skirts the river from Cremorne Gardens to the pumping station at the upper end of the Low-Level sewer. The Fulham branch commences at Putney Bridge, and joins the Chiswick line at the King's Road. The Acton branch commences at Stamford Brook, Wormwood Scrubs, passes along the Uxbridge Road to the Counter's Creek sewer at Royal Crescent, Notting Hill, and then turns to the south, and in nearly a straight direction joins the Chiswick sewer near Cremorne Gardens.

The Chiswick line of sewer is 3¼ miles long; the Fulham sewer 1 mile 720 feet, and the Acton branch 1½ mile. The size of the main line varies from 4 feet by 2 feet 8 inches, to 4 feet 6 inches diameter, with a fall of 4 feet per mile, the depth below the surface being from 14 to 30 feet. The Fulham branch varies in size from 3 feet 9 inches by 2 feet 6 inches, to 4 feet 6 inches by 3 feet, its fall 10½ foot per mile, and its depth below the surface about 17 feet.

The works of this Western District were principally executed in gravel, charged with large volumes of water, which very much impeded the progress of the work. The difficulty was overcome by laying stoneware pipes under the inverts of the sewers to convey the water to powerful steam-pumps, and by this means the works were successfully carried out. The sewers were also successfully carried, in this treacherous subsoil, under railways and canals without any serious accident or failure.

There are two very important low-lying districts in the East, also drained by the Low-Level sewer—Hackney Wick and the Isle of Dogs. The branch draining the former of these districts commences at Homerton, to the north of the Northern High-Level sewer, but too low to be relieved by it. From Homerton it passes under the Northern Outfall sewer, and along the west bank of the River Lea, and falls into the Low-Level sewer, thus intercepting the sewage of a large district, and preventing it falling into the River Lea. The Isle of Dogs is an extensive district, too low to admit of efficient drainage without a resort to pumping. This district, although at no very remote period it was a stagnant marsh, is now becoming rapidly covered with factories and various descriptions of works along the banks of the river, and in the interior by the dwellings of workmen, and it is therefore a matter of considerable importance that an efficient system of drainage should be adopted.

The length of the main-line Low-Level sewer is 8¼ miles, and its size varies from 6 feet 9 inches to 10 feet 3 inches in diameter, with an inclination ranging from 2 to 3 feet per mile. It is provided with storm overflows into the river. The length of the two above-named branches is about 4 miles.

SOUTH SIDE OF THE THAMES.

There are no engineering works of any importance on the south side of the Thames, with the exception of the pumping stations at Deptford, and at the outfall into the Thames at Crossness. In the execution of the intercepting sewers on the south side, however, there were many difficulties to contend with, consequent upon the nature of the strata and other local peculiarities rendering it absolutely certain that in this case, as in all other engineering operations, these exceptional and unforeseen difficulties can only be overcome by the ingenuity and scientific resources of the engineer carrying out the works.

Some very successful operations were executed of tunnelling under railways—such, for example, as under the South-Eastern and the Brighton Railways, near the New Cross stations on these lines, where two parallel lines of sewers were carried but a very little distance under the permanent way of these railways, without stopping the traffic.

Much difficulty was also experienced in executing the works under the foundations of the arches of the Greenwich Railway, in consequence of the treacherous nature of the soil. The sewer was carried under Deptford Creek, and the navigation kept open by constructing a coffer-dam into the centre of the Creek, and executing half of the work at a time.

Several portions of the Metropolitan Drainage Works, on each side of the Thames, were executed in quicksand; and the difficulties heretofore experienced in drawing off the water without carrying the sand with it were successfully overcome by Mr. Bazalgette, in the following manner. Brick wells were built in any convenient

position near the works, and carried down 5 or 6 feet below the lowest part of the excavation, and the bottom and sides of the well were lined with shingle, which excluded the sand, and allowed the water to percolate through into the well, from which it was pumped up.

The bricks used in the works were the best stocks, and the inverts were occasionally lined with Staffordshire blue bricks. In the lower portions of the sewers, the brick-work has been laid in Portland cement mixed with an equal proportion of sand; and in the upper part of the sewers, blue lias lime-mortar was used, mixed in the proportion of 2 of sand to 1 of lime. In some cases, however, the whole of the work was executed in Portland cement.

The cement used was the best quality of Portland cement, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a tensile breaking weight of 500 lbs. on $2\frac{1}{4}$ square inches, seven days after being made in an iron mould, and immersed in water during the interval. The severe tests employed by the engineers of the Board of Works have tended very much to the improvement of the manufacture of Portland cement, as manufacturers used every possible effort to come up to the required standard.

Much valuable information upon the very important subject of Portland cement, and the modes of testing its qualities, may be obtained by reference to a paper presented to the Institution of Civil Engineers, in 1865, by Mr. John Grant, M. Inst. C.E., called "Experiments on the Strength of Cement, chiefly in reference to the Portland Cement used in the Southern Main Drainage Works."

DESCRIPTION OF PLATES.

Plate 1 is a map of London, containing the whole of the drainage area embraced by the operations of the Metropolitan Board of Works, and showing the direction of the main lines of intercepting sewers, also the position of the outfalls and of the pumping stations.

Plate 2 shows the mode in which the Mid-Level intercepting sewer passes under the Regent's Canal near the south-west angle of Victoria Park. In approaching the canal, the sewer is circular, 10 feet 6 inches in diameter, consisting of four half-brick rings; but in order to retain the present depth of water in the canal, it was necessary to depress the crown of the sewer 2 feet, and to adopt the form shown by the cross section taken at G H on plan, with vertical sides, a flat segmental base, and horizontal top. The length of the sewer under the canal is 100 feet, and the top is formed of cast-iron girders 1 foot 3 inches deep, and placed 5 feet from centre to centre, filled in between with brick arches in half-brick rings, with some concrete over to bring the bottom of the canal to a uniform level. In order to give a flat top to the sewer, cast-iron plates 1 inch thick, with strengthening flanges on the upper side, are introduced, resting on the bottom flanges of the cross girders.

Plate 3 shows the mode in which the Mid Level intercepting sewer passes over the Fleet sewer, and also forms a junction with it by a storm overflow. The plan on this plate shows the mode of crossing the Fleet sewer and of passing off the storm waters into that sewer. The overflow being only 2 feet deep at the point where it leaves the sewer, it was necessary to elongate the space in order to obtain a capacity equal to that of the 4 feet diameter iron pipes which constitute the overflow sewer. This capacity, however, appears to unnecessarily increase, as the length is 18 feet, which, with 2 feet deep, gives a sectional area of 36 feet, rapidly converging into a pipe of 4 feet in diameter. Sections on A B and G H show the outfall or overflow pipe, and the manner in which it is connected with the Mid-Level and Fleet sewers; section D C shows the front of the storm overflow chamber; and section C D shows the junction of Coppice branch sewer with the intercepting sewer. There are also various other matters of detail on this plate which will be easily understood when referred to the principal parts to which these details belong.

Plates 4, 5, and 6 show the manner in which the outfall sewers are carried over the River Lea; and there being a roadway constructed over the sewers, gives to this work some degree of engineering interest.

The sewers are supported between malleable iron longitudinal girders about 10 feet above the top water of the river, and the roadway is supported by transverse girders of triangular construction, resting upon the longitudinal girders. The roadway is 24 feet wide with a 6 feet footway on each side supported by cantilevers projecting from the end of the girders, and a series of light longitudinal girders support road plates on which are placed concrete and stone pitching.

The principal portions of this structure, as well as the numerous details, are minutely described on the plates, and do not require any further general description here.

Plate 7 shows a plan and section of bridges over Marsh Lane, the North Woolwich Railway, and the Bow and Barking Junction Railway. The thoroughfares are passed under the sewers, three in number, from the Abbey Mills pumping station downwards, and over the sewers a roadway is constructed 35 feet 6 inches in the clear between the parapets, including footways. The outfall sewers being reduced to a minimum fall of 2 feet per mile, which could not be altered, it was necessary that all thoroughfares crossed by the sewers should yield to this necessity. There are no peculiarities connected with these bridges which require to be pointed out.

Plate 8 shows the plan and elevation of a bridge carrying the three sewers and an upper roadway over the main line of the Bow and Barking Railway.

Plates 9 and 10 are the details of the above bridge.

These several details, if carefully studied, will be sufficient to give a correct idea of the mode in which the several parts of the structure are connected together.

Plates 11 and 12 represent the plan, section, and details of a bridge over the feeder to the East London Waterworks. This bridge is situated on the upper side of the Abbey Mills pumping station, and consequently there are only two tubes or sewers. These sewers are placed about 5 feet above the level of the water, with a roadway over the sewers 24 feet wide with two 6 feet footways. The details on Plate 12 are numerous and explicit, and described on the plate with sufficient minuteness.

Plate 13 is a plan of the lower portion of the outfall sewer, with the reservoir on one side of it. The reservoir is 16¾ feet average depth, divided by partition walls into four compartments, covering altogether an effective area of about 9½ acres, and is constructed for the purpose of storing the sewage during 11 hours of each tide, so that it may be permitted to fall into the river only at the beginning of the ebb tide. The bottom of the reservoir being about the level of low-water in the river, it is necessary to unite the sewage from the outfall sewers with the sewage issuing from the reservoir, in order that the combined mass shall overcome the resistance of the head of water in the river. The external and partition walls of the reservoirs are composed of brickwork, and the entire area is covered by brick arches supported upon brick piles, and the whole is covered by an embankment of earth rising about 2 feet above the crown of the arches.

Plates 14, 15, and 16 show the details of reservoir and of the several penstocks, exit culverts, valves, &c.

Plate 17 shows the junction of the Bermondsey branch of the Low-Level sewer with the Duffield sewer at the commencement of the branch. The details of the junction, and of the penstock connected therewith, are also contained upon the plate. The same plate contains the plan and details of the junction of the branch sewer with the Earl sewer at Deptford Lower Road.

Plate 18 shows the details of the junction of the Bermondsey branch with the Low-Level sewer, and also the penstocks and penstock chambers connected with the arrangements at this junction.

From this junction the Low-Level sewer extends to the Deptford pumping station, where the sewage of the main line and branch is raised a height of 18 feet into the southern outfall sewer, and, together with the sewage of the two High-Level sewers, conveyed to the Outfall pumping station at Crossness.

Crossness pumping station, taken as a whole, is the most important engineering work connected with the Metropolitan Drainage Works. The Abbey Mills pumping station has a greater pumping power, being capable of raising 15,000 cubic feet of sewage per minute a height of 36 feet, whilst the quantity to be raised at Crossness is ordinarily 10,000 cubic feet per minute, and the lift varying from 10 to 30 feet; still the four reservoirs, covering an area of 6½ acres in extent, and the complex nature of the penstock and other arrangements, renders the Crossness works, as a whole, highly interesting.

Plate 19, Fig. 1, shows a plan of the Outfall sewer, the reservoirs, engine and boiler-houses, penstocks, discharging culverts, &c.

The sewage may be sent into the river direct from the Outfall sewer at or near the time of low-water, but is ordinarily sent in by the main culvert to the pump well, whence it is raised into the reservoirs, passing through the upper culvert, and discharged during the two first hours of the ebb tide by the middle culvert, and during the time of discharge the sewage raised by the pumps is sent direct into the river. Figures 2, 3, and 4 are transverse sections; and 5, 6, and 7 are details of river wall.

Plates 20, 21, 22, and 23 contain the several details of the upper, lower, and middle culverts, the penstocks and penstock chambers, and the arrangement of a direct outlet from pumps to river.

Plate 24 shows plans and sections of ventilating shafts, side entrances, weirs, junctions, and storm overflows.

THAMES EMBANKMENT.

THE history of inventions, discoveries, and improvements in the several branches of scientific investigation, which can be presented to the human mind in its progressive stages from rude barbarism to the highest point of refinement to which the intellectual faculty of man has yet attained, presents almost universally a gradual development, and very seldom exhibits strongly marked and abrupt steps taken in advance. In consequence of the intimate connection which subsists between the several branches of human knowledge and of the laws which govern the material universe, and the aid which a knowledge of one branch or of one law fo

nature affords as a key to collateral branches, and to the investigation of natural laws, it seems but reasonable to award more credit to the first crude idea or suggestion in furtherance of the invention or improvement of anything tending to the benefit of society than to more important steps taken at a more advanced period of mechanical and scientific improvement.

In the rude ages of society, great inventors were frequently deified, and swelled the long list of mythological celebrities; and indeed there is still a tendency, even in this country, and in this enlightened age, to a species of hero-worship among the uninitiated, and more particularly among those who have not a near or microscopic examination of the heroes who are thus placed upon the pedestal of fame. In tracing the history of any invention, it will be found that the first germ of the subject is lost in the pre-historic period; and as the subject is traced along its several stages, a portion of the credit of the invention must be awarded to so many parties, that there is no individual standing out so very prominently as to entitle him to any more credit than that of a successful grouping together and utilising the ideas of previous labourers in the same field, and of adding his own quota more or less to the previous stock of knowledge on the same subject. The prejudices of the age in which an inventor lives, and the apparent dread of innovation which possesses the multitude, must also be taken into the account in awarding the proper meed of praise to all parties concerned. With reference to the Thames Embankment now in progress under the direction of the Metropolitan Board of Works, this gradual accrument of efforts towards the realisation of the projects now being carried out, have been in operation beyond the reach of authentic history; and whether the perfection now aimed at, after so many efforts in past ages to improve the Thames, will prove satisfactory or not, time alone can tell.

In this eminently practical country, however, a very prominent position is always awarded to the person who successfully carries out a project, which may have been under consideration in various stages of development, and contending with ignorance and conflicting interests for centuries; and no doubt when the embankment works, and the drainage connected therewith, have been successfully carried out, due credit will be given to the Metropolitan Board of Works, to the engineer-in-chief to the Board, and to the resident engineers acting under him.

In Stow's "Survey of London" it is stated of the Thames: "That this famous stream hath her head or beginning out of the side of an hill standing in the plaine of *Cotswold* in Gloucester shire, about a mile from Tetbury in the same county." . . . . "From hence it runneth directly to the East, as all good rivers should do." . . . . "Our famous river being thus brought to London, and hasting on a pase to meet with *Oceanus* her amorous husband." . . . . "What should I speake of the fat and sweet salmon daily taken in this stream, and that in such plenty as no river in Europe is able to exceed it." There are also a great variety of other kinds of fish enumerated which were found in great quantities in the River Thames before its waters were polluted by sewage and other deleterious matters. Whether the most perfect system of sewage and embanking which can be carried out can ever restore the Thames to its pristine state may be considered very doubtful.

History does not appear to afford any trace of the time when the embankment of the Thames from Sheerness to London was accomplished. The probability is that it was executed by the ancient Britons by compulsory labour under the superintendence and coercion of the Romans.

The earliest fragments of information which can be obtained respecting the embanking and improving the River Thames, refer to some existing law of previous construction. The first *authentic* information which can be obtained on the embankment of the Thames does not extend beyond the reign of Edward II. in the year 1367, when "John Abel and John de Hortone, being then by the King's letters patent constituted commissioners for to view and take order for the repair of the banks, ditches, &c. for the safeguard of those from the overflowing of the tide, which lie between Dertford, Flete, and Grenewich." "And not long after this, John de Ifeld, John de Hortone, and Will de Northo had the like commission for the very same marches."

Patents and commissions of the above description continued to be issued very frequently for small portions of the banks of the Thames, or for the repair of specified breaches which had taken place. This very inefficient mode of guarding and repairing the banks of the river was continued to the reign of Henry VIII., when the subject was frequently brought before Parliament; and several Acts were passed in his reign, and in the reign of Elizabeth, for the preservation of the banks and improvement of the navigation, and the subject thus began to be treated on a more uniform and a more extended scale.

In 1695 an Act was passed to "Prevent Exactions of the Occupiers of Locks and Wears upon the River Thames westward, and for Ascertaining the Rates of Water Carriage upon the said River."

In Sir Christopher Wren's plan for rebuilding the City of London after the great fire of 1666, it was proposed to construct a solid embankment wall, or quay, from the Temple Gardens to the Tower; and in consequence of this proposal, an Act was passed in 1668 to prevent the erection of buildings within 40 feet of the river bank between the Tower and the Temple. This 40-foot way was to have very extensive ranges of warehouses built on the side of it, to meet the wants of the several descriptions of trade carried on in the port of

London. Encroachments were, however, soon made, and the Act was ultimately repealed in 1821.

The next public measure of any importance took place in 1767, when, in connection with the completion of Blackfriars Bridge, the river frontage from Paul's Wharf up to and including Temple Gardens was embanked under the direction of the late Mr. Mylne. This improvement, although partial and limited, was the greatest modern embanking operation which had at that time been executed on the Thames. The object, however, was merely local, as may be seen from the following statement: "To remove the accumulations of mud, filth, and rubbish from the City side, which had rendered the wharfs inaccessible even at high-water, was extremely offensive, and in summer often dangerous to the health of the neighbouring inhabitants."

The next attempt to embank any portion of the Thames took place in 1770, when it was proposed to throw a solid embankment 100 feet into the river in front of Durham Yard, now the Adelphi Terrace. The Act to effect this object was strenuously opposed by the Corporation of London, and by several other parties. The subject was investigated by a Committee of the House of Commons, and much contradictory evidence was laid before the Committee on the advantage to be derived from embanking on the one hand, and the injury to the river, as a navigable channel, on the other. Sir Charles Knowles stated "That the only thing that can possibly be done for the preservation of the navigation of the River Thames is the making of wharfs. That it is a known principle in hydraulics that wherever water can spread upon the surface, it diminishes its velocity; therefore contracting its channel will certainly augment it, wear its bed deeper, and render it more navigable. That the embankment mentioned in the petition being partial, will have a partial effect; but if this effect will be found good, embankments will soon become general. That a greater embankment would be a greater advantage, and that embankments would not obstruct the flood-tide."

The opposition was principally carried on by lightermen, with some questionable engineering evidence.

A Mr. Charles Holmes states that he finds, from surveys of the river, that it has shoaled as much as three feet in the centre in about thirty years, and that "in about eighty years he calculates the Thames will be filled up on a level with the land;" also that "he denies the principle of the velocity of water being able to scour the beds of rivers." The Committee, however, resolved "That the petitioners, John, Robert, James, and William Adam, &c., have fully proved the allegations of their petition, and that the House be moved for leave to bring in a Bill for embanking a certain part of the River Thames, near Durham Yard, within the liberty of the City of Westminster, and County of Middlesex."

The third Report of the House of Commons upon the improvement of the port of London, dated 28th July 1800, contains the following statement: "A second point for consideration, and of much greater importance, is the embankment and improvement of the shores. Referring to the several plans in the Appendix for the particular proposal of each of the architects already named, and also to a very curious paper drawn up by Mr. Jessop on this subject, accompanied by a section of the river, showing its present width, depth, and form, and proposed improvement, your Committee beg leave to observe in general that a considerable embankment on the northern shore would not only be useful in deepening the channel of the river, but might prove the means of defraying a great part of the expense of the whole of the system of improvement; as the value of the space gained from the river, either to be employed as wharfs or warehouses, would greatly exceed the cost of the work; and it might be desirable to remove so much of the shore on the Surrey side, where the ground is of much less value, as to straighten the course of the river, and allow for a large embankment on the London side, without reducing the width of the river in any part below the width which it now has opposite to Old Swan Stairs; and it is obvious that the gravel and soil removed in ballasting away the shoals in the river may be advantageously employed in filling up the embankment on the shore, and forming foundations for warehouses."

The subject of the improvement of the Thames below London in the lower reaches of the river to its mouth, the portion passing through the metropolis, and the complicated and conflicting interests connected with the navigation and drainage of the Upper Thames, was seldom allowed to remain long without some efforts to arrive at something like a perfect system of improvement and of administration. Great embarrassment was, however, occasioned by a disputed jurisdiction, the Corporation of the City of London and the Government being at issue upon many important points.

In 1831, Sir John Rennie, Mr. Telford, and Mr. W. C. Mylne were called upon by the Corporation to report upon the navigation and embanking of the River Thames. Mr. Telford could not attend, and the Report was made by Sir John Rennie and Mr. Mylne.

The following points were considered by them:—

First. The preservation and improvement of the navigation.

Secondly. Increased facilities and accommodation to the adjoining shores.

Thirdly. The practicability of constructing quays.

Fourthly. The expense and probable returns for the sums expended.

It is very evident from this Report that the anticipated alteration in the *régime* of the river in consequence of the removal of Old London Bridge, then about to be effected, prevented the reporters from arriving at any

very definite conclusions upon any of the subjects under investigation.

It is stated in the Report that "The attempt to lay down a definitive line for the quays at present, until the effects of the removal of the old bridge shall have been fully ascertained, would be attended with considerable difficulties."

Under the third head it is stated that "These quays should be constructed in a durable manner, at the same time unnecessary expense might be avoided. They should be founded a sufficient depth below the bed of the river, so as to prevent them from being undermined by the increased velocity of the current, and to be generally faced with brick, and with stone only when the proprietors themselves may choose to do so."

"Fourth. A fund to be raised from the wharfingers to defray expenses."

The Report concludes by stating that, "Upon the whole, therefore, viewing this important subject in every possible manner, we are decidedly of opinion, either as regards the improvement of the navigation, or the salubrity and ornament of the metropolis, that some such arrangement as now proposed for regulating the line of wharfs, should be carried into effect as early as possible after the removal of Old London Bridge."

In 1840 a very important step was taken by the Corporation of the City of London, in having a line laid down on each bank of the river (known as Walker's line) beyond which no projection would for the future be allowed; and as these lines were laid down with the view of giving the best possible direction to embankments or training walls which, in future, would be carried out even if the operations were in detached portions, it is much to be regretted that a measure of this kind was delayed so long.

In 1844 a Commission was appointed "to consider the most effectual means of improving the metropolis." This Commission, however, devoted much of its time to the improvement of the navigation of the River Thames, and to the formation of embankments on the north and south sides of the river from Vauxhall to London Bridge.

The Report of the Committee contains the following statement, that "Upon a careful review of the many subjects of improvement, for which plans had already been before the public, or were subsequently submitted to us, we consider AN EMBANKMENT OF THE RIVER THAMES to have the first claim to our attention."

Sir Frederick Trench spent much time in endeavouring to promote an embankment of the Thames on the north side. He proposed to adopt the outline of the river as laid down by Mr. Walker, and to construct a railway upon pillars passing over the dock entrances. This plan was ultimately abandoned.

The most indefatigable advocate for a Thames Embankment was a Mr. John Martin, whose plans, although reported against by the Commission, approximate more nearly to the plans which are now being carried out than the plans of any other projector. The principal features of the several plans proposed by Mr. Martin were a solid embankment, with roadways and promenades, occupying some of the reclaimed land for building purposes; the interception of the sewage from the river, and the utilization of it for agricultural purposes. The Commission doubtless considered that the time had not arrived when a clean sweep could be made of all the river-side traffic without an overwhelming amount of compensation.

The plan proposed by Mr. Walker was confined in its outline to the line he had laid down for the Corporation of London some years previously. Mr. Walker's plan comprised an embankment between London and Vauxhall Bridges, on both sides of the river, with openings for wharfs at the following places on the north side:—At Northumberland Wharf, about 500 feet; at Waterloo Bridge, extending to the bridge stairs, about 800 feet; near Temple Gardens, about 400 feet; and a fourth, commencing at Whitefriars Dock and terminating at Blackfriars Bridge Stairs, 700 feet in extent. These docks prevented the possibility of the formation of a roadway which, however desirable, formed no feature in Mr. Walker's plan; he proposed, however, as a supplement to his plan, if it was considered desirable, to construct a raised terrace, 50 feet wide, supported on flat arches of 100 feet span, and communicating with Hungerford, Waterloo, and Blackfriars Bridges, at the level of their respective roadways.

Mr. Walker's plan had excited considerable opposition in Parliament in 1840 from the wharfingers and others interested in the trade of the locality over which his embanking operations extended. Much conflicting and even very doubtful evidence was given upon the question of the diminished quantity of tidal water which would flow up the river after the embankment had been completed. This is, however, a point upon which great diversity of opinion exists among engineers. Mr. Walker's plan was principally directed to the improvement of the River Thames, and not to the increase of thoroughfare accommodation along the banks of the river. The plan was intended to effect—

First. "To bring the River Thames to a more uniform width than it is at present, by means of embankments."

Secondly. "To improve the present river lines where the ground is not built upon, by easing the present quick curves."

Thirdly. "To remove the shoals by dredging, and to form the bottom of the navigable channel to a regular line."

Fourthly. "To continue the covered sewers out to the front of the proposed embankment, where they may discharge below the level of low-water."

Fifthly. "To avoid the heavy claims that might be

made for interference with the coal and timber traffic, the above docks were allowed to remain as breaks in the continuity of the embankment."

Mr. Page laid before the Commission a "Plan of part of the River Thames in the seventeenth century, showing successive encroachments." These encroachments consist, for the most part, of embankments which had been authorised by Parliament, but being in detached portions, and forming no general outline, must have acted injuriously upon the river.

Mr. Page supplied much valuable information to the Commission upon the state of the river, and the alterations which had taken place in the bed and banks of the river in consequence of the removal of Old London Bridge and various other causes.

Mr. Page submitted several plans for embanking the river from the Penitentiary to some distance below Blackfriars Bridge, but with continuous docks on both sides of the river. The dock entrances were numerous, and would, consequently, very much diminish the advantages which would otherwise result from an uninterrupted communication for traffic, or as a promenade.

Modifications of Mr. Page's plan were also laid before the Commission by Mr. Cubitt and Mr. Rendel, but the proposed modifications did not materially alter the principle of the plan, but gave generally an increased amount of solid embankment, and a more convenient roadway.

A plan was also laid before the Commission by Mr. Barry, one of its members, "for embanking the River Thames on both sides, from Vauxhall to London Bridge, upon the levels of the present wharfs, gardens, &c.; for providing private docks or slips for each wharf, or for two adjoining wharfs; and for forming a public road from London to Vauxhall Bridge, on the Surrey side of the river,"—the road to be formed upon arches, upon such levels as would coincide with those of the roadways of the several bridges with which it would communicate. This plan, if carried out to its full extent, would tend very much to embellish the southern bank of the Thames; but it would render the northern bank of the river very much uglier than it ever has been, inasmuch as it is proposed greatly to increase the number of docks and to project them a considerable distance into the river; and these extended wharfs were intended to afford "the means of forming depôts for coals, &c. and of erecting warehouses or sheds for loading and unloading wagons under cover upon the portions of solid embankment between the proposed docks or slips."

In 1851 a pamphlet was published by a Mr. W. H. Smith, "London, Not as It Is, but as It Should Be: a Plan to relieve the Street Traffic, purify the Thames, remove the Sewage, give abundant House Water, and form a Junction of all the Railways within the Thames Embankment, by means of one Reproductive Undertaking."

Projects of this description generally break down in consequence of an attempt to combine too many operations in one general scheme. The authors of this class of contemplated improvements appear to have an excess of ingenuity or a great deficiency in working out details in order to ascertain whether one part of a project may be inconsistent or not inconsistent with another part of it.

In 1860 a Committee of the House of Commons examined several projects for embanking the northern shore of the river between Westminster and Blackfriars Bridges. Some of the projects contemplated very extensive building schemes upon the land reclaimed from the river, consisting principally of bonded warehouses.

In 1861 the Thames Embankment Commission was appointed, "to enquire into plans for embanking the River Thames *within* the metropolis," so as to "provide with the greatest efficiency and economy for the relief of the most crowded streets, by the establishment of a new and spacious thoroughfare, for the improvement of the *navigation* of the river, and which will *afford an* opportunity of making the Low-Level sewer without disturbing the Strand or Fleet Street, and also to report upon the cost and means of carrying the same into execution."

The Commissioners adopted the usual, but not very creditable plan of begging for assistance, and the admission of their incapacity to grapple with the subject entrusted to their investigation "was made known to the public by advertisement in the newspapers, and more than fifty plans were presented for our consideration."

The projectors of these several plans not having the advantage of perusing the mass of evidence elicited during the investigation upon the nature, extent, and value of the traffic along the site of the proposed embankment, *could not* possibly arrive at anything like a definite idea upon the whole question. Had such evidence been laid before intended projectors, it is very probable that a better plan would have been produced than that proposed by the Commission.

The Commissioners, with one exception, were of opinion "that the control and management of the undertaking should be entrusted to a special Commission appointed by your Majesty, in order to ensure the speedy and economical attainment of an object so much needed by the public, and affording so favourable an opportunity for the improvement of the river and the adornment of the metropolis."

Had this recommendation been acted upon by the Government there can hardly be a doubt that the *special* Commission would be composed principally, if not entirely, of members of the Commission who had made the recommendation, and who were so intimately acquainted with the several bearings of the whole subject

from the mass of facts, figures, and plans which had been laid before them.

DESCRIPTION OF PLATES.

Plate 25 shows a front elevation of the granite facing to the embankment wall, built header and stretcher in uniform courses. The granite facing commences 2 feet below the mean level of low-water, and is carried up to a height of 4 feet above Trinity high-water mark, with a solid parapet 3 feet 6 inches high. The longitudinal and transverse sections on this plate show the Low-Level intercepting sewer constructed at the back of the granite facing, and its brick backing giving breadth and consequent stability to the whole structure. The sewer is circular, 7 feet 9 inches in diameter at Westminster Bridge, and increasing to 8 feet 3 inches at the lower end. This appears to be a very small increase in the capacity of the sewer to meet the augmented quantity of sewage which would flow into it from the several local sewers forming junctions with it. There is a subway constructed over the sewer 9 feet by 7 feet 6 inches.

Along the river face of the embankment wall there will be a promenade about 40 feet average breadth, beyond which there will be a public road for all description of traffic.

Plates 26 and 27 show the arrangement for a steamboat landing-pier near Westminster Bridge. The recess in the embankment wall for the reception of the floating pier or dumby is 250 feet long by 29 broad, for 90 feet in the centre and 18 feet broad, for 80 feet long at each end.

Access to and from Westminster Bridge is attained by three flights of steps, and by a descending ramp or passage of only 8 feet in width, and from the embankment terrace by a similar ramp or passage at the opposite end of the dumby. The space under the three flights of steps is made available for the collection of water at high tide, to be used in flushing the floor of the recess. The details of mouldings and other matters connected with this position of the works will be easily understood, as the dimensions are legibly marked.

Plate 28 shows the plan, section, and the necessary details of a landing-stairs between Charing Cross and Waterloo Bridges. The landing-stairs consist, generally, of a few steps placed at right angles to the river wall, descending on to a platform or landing 50 feet by 18 feet 9 inches, from which a flight of steps parallel to the river wall descend on each side to the foreshore.

The space beneath the steps and landing is so constructed as to serve for a reservoir for the storage of tidal water to be used for flushing purposes.

This work will form an ornamental feature in the general embankment works.

Plate 29 represents a plan, elevation, and section of landing-stairs at York Gate, and Plate 30 represents the several details of the work. The existing structure at the bottom of Buckingham Street is to be reconstructed as a central ornament to these landing-stairs. The details of this work are so minutely delineated and explained on Plate 30 as to supersede the necessity for any general description.

Plate 31 shows a plan, section, elevation, and some of the details of the overflow and outlet sewer at Savoy Street. The mouth of the overflow sewer is covered by a hanging flap valve to exclude the tidal water; consequently there can be no overflow from the sewer into the river unless the pressure is greater on the inside of the valve than it is on the outside, and this will depend upon the relative height of the water in the river, and the sewage in the overflow chamber.

Plates 32 and 33 show the plans, sections, and elevations of penstocks, penstock chambers, and the necessary gearing for the overflow and outlet at Savoy Street sewer.

Plate 34 contains plan, section, and elevations of steamboat pier at Waterloo Bridge. There is a recess on each side of the first pier of the bridge about 180 feet long, with a mean breadth of about 27 feet. The pontoons, screen walls, and other arrangements are similar to those at Westminster Bridge.

At the centre and ends of the recesses, projecting piers are constructed, surmounted by blocks or pedestals for the reception of statuary.

Plate 35 shows the manner in which the foundation of the pier of the bridge is secured, the foundations of the new works being carried lower than the foundation of the piers of the existing bridge.

Plate 36 contains the several details of the works shown on Plates 34 and 35.

Plate 37 shows the junction of Northumberland Street and Craven Street sewers; and from the junction of these sewers a sewer is constructed conveying the contents of both into the Low-Level intercepting sewer.

Plate 38 shows plans and sections of gullies, ventilating grates, &c. &c.

NOTE.—We had intended giving some particulars respecting the iron caissons, but circumstances have transpired which prevent our doing so for the present.

END OF VOLUME FOR 1865.

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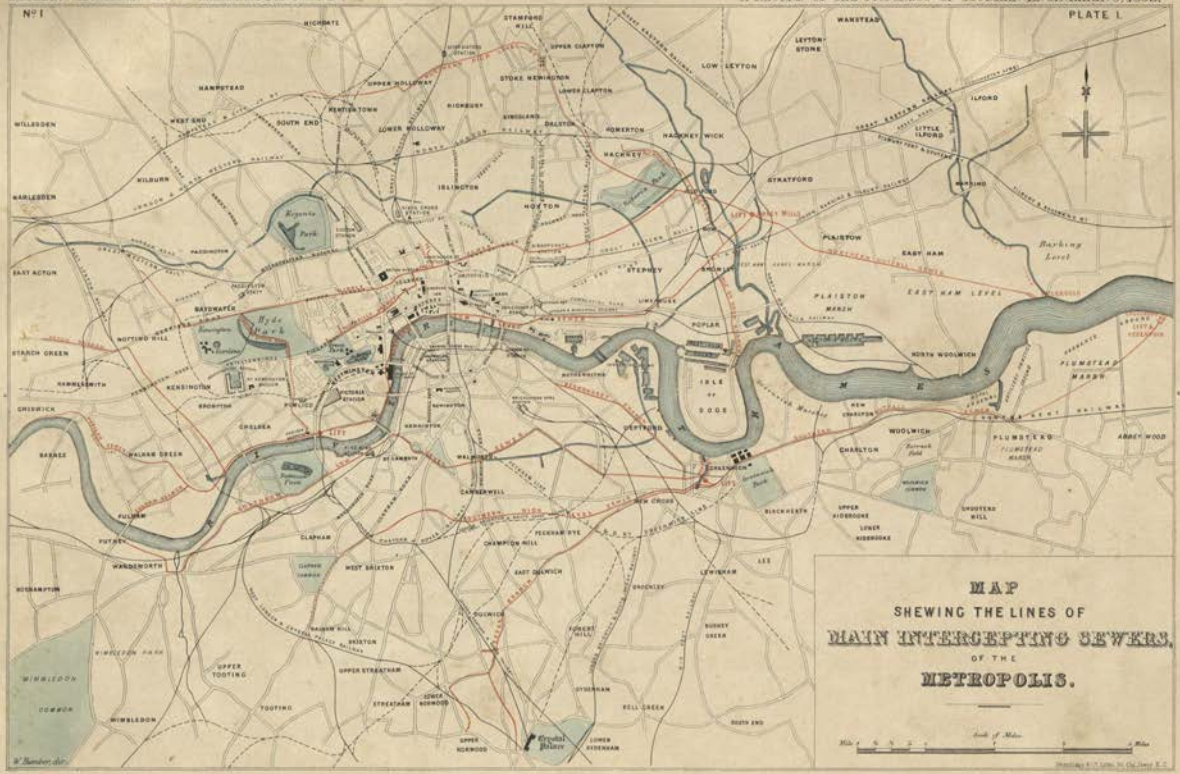
No I
PLATE I.
MAP
SHEWING THE LINES OF
MAIN INTERCEPTING SEWERS,
OF THE
METROPOLIS.
HIGHGATE
HAMPSTEAD
WILLESDEN
KILBURN
HARLESDEN
EAST ACTON
STARCH GREEN
HAMMERSMITH
CHISWICK
BARNES
PUTNEY
WANDSWORTH
BATTERSEA
KENSINGTON
CHELSEA
PIMLICO
WESTMINSTER
ISLINGTON
HACKNEY
STRATFORD
PLAISTOW
EAST HAM
WOOLWICH
CHARLTON
PLUMSTEAD
ABBEY WOOD
DEPTFORD
GREENWICH
LEWISHAM
CAMBERWELL
BRIXTON
CLAPHAM
TOOTING
WIMBLEDON
UPPER TOOTING
STREATHAM
DULWICH
SYDENHAM
BELL GREEN
SOUTH END
LEYTON
LEYTONSTONE
WANSTEAD
ILFORD
LITTLE ILFORD
BARKING
Regents Park
Hyde Park
Victoria Park
Finsbury Park
Crystal Palace
Barking Level
EAST HAM LEVEL
PLAISTOW MARSH
PLUMSTEAD MARSH
ISLE OF DOGS
THAMES
Scale of Miles
Miles
W. Bamber del.
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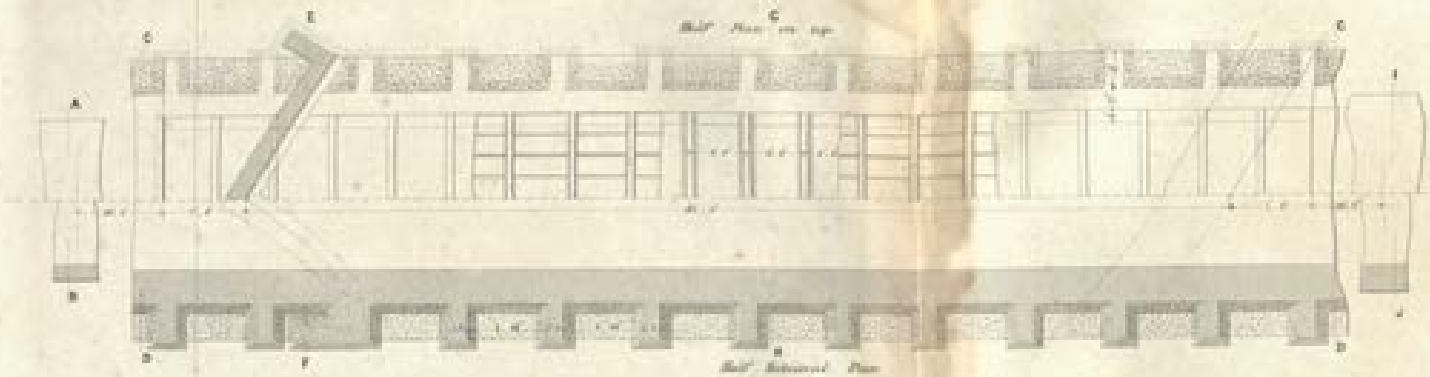
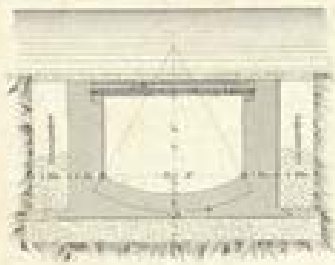
MAIN DRAINAGE METROPOLIS.
N° 2.

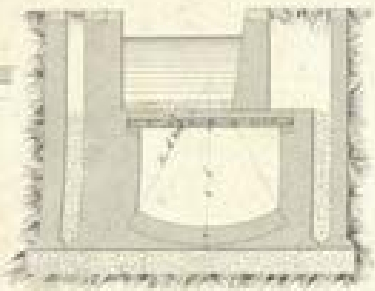
MIDDLE LEVEL SEWER.

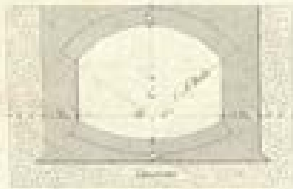
SEWER UNDER REGENTS CANAL

A RECORD OF THE PROGRESS OF MODERN ENGINEERING. 1865.
PLATE 2.



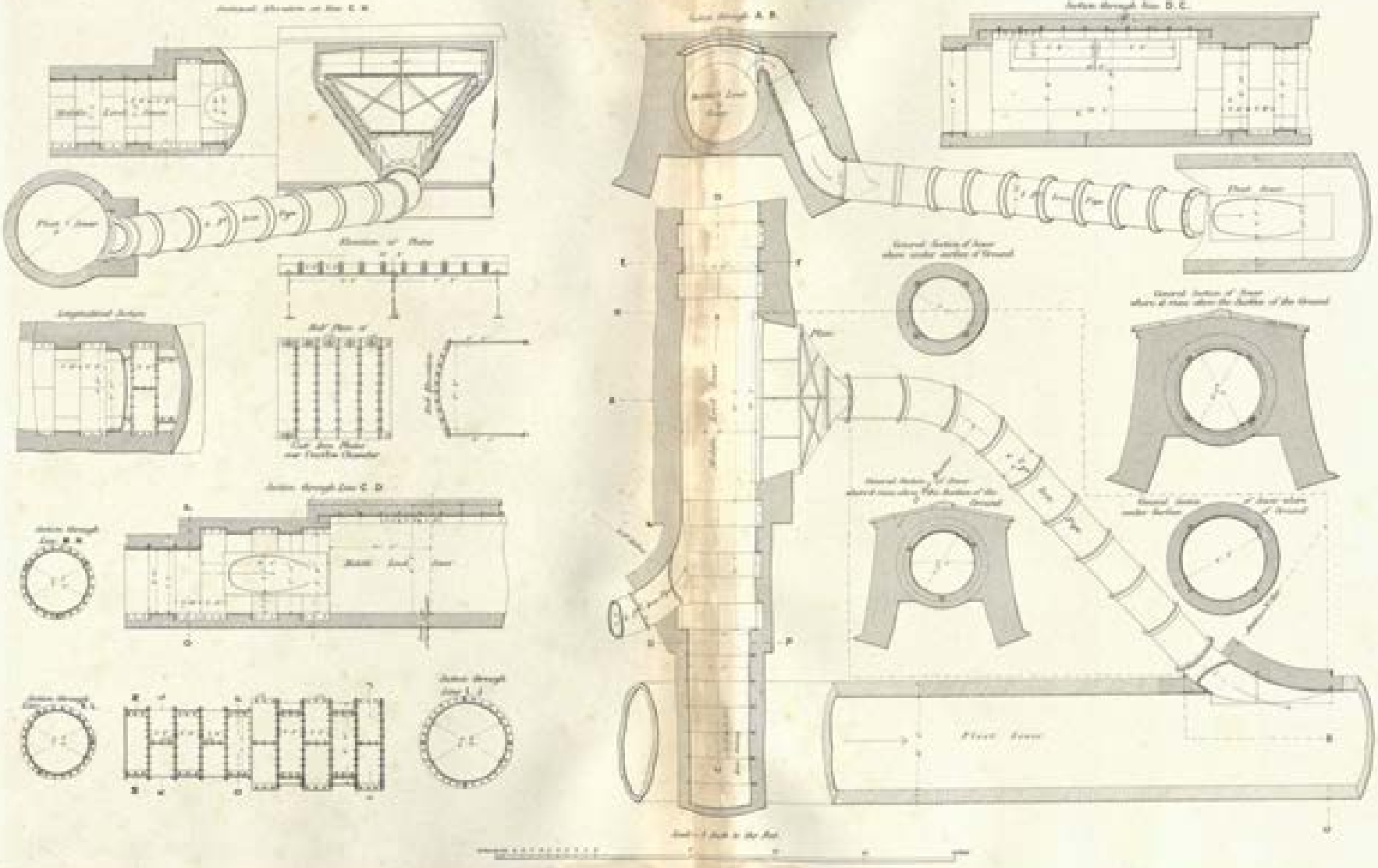






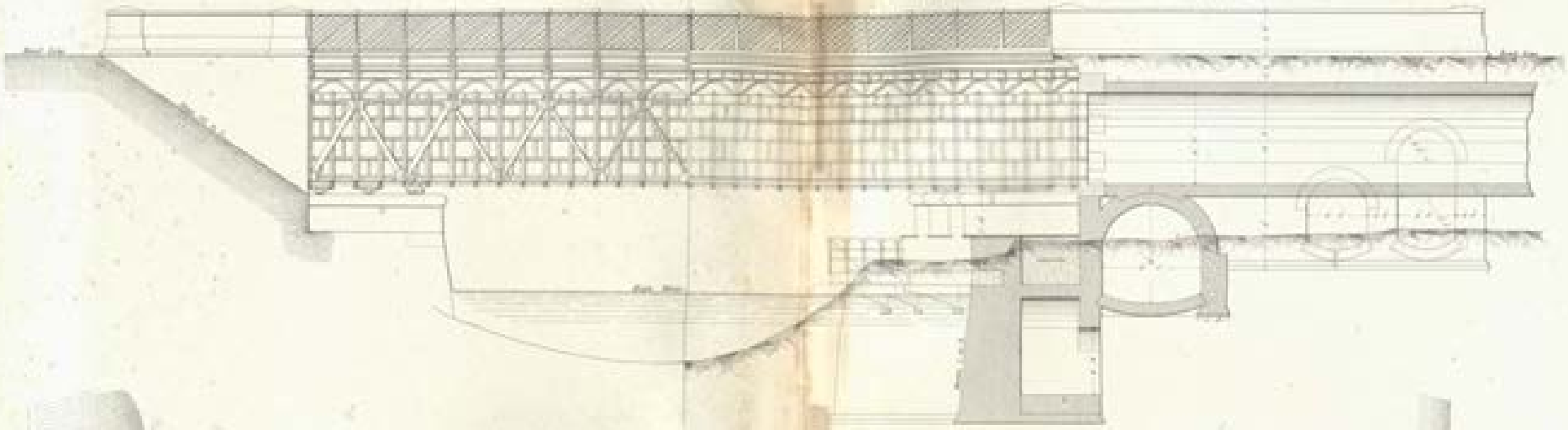
MAIN DRAINAGE METROPOLIS.
N° 1.

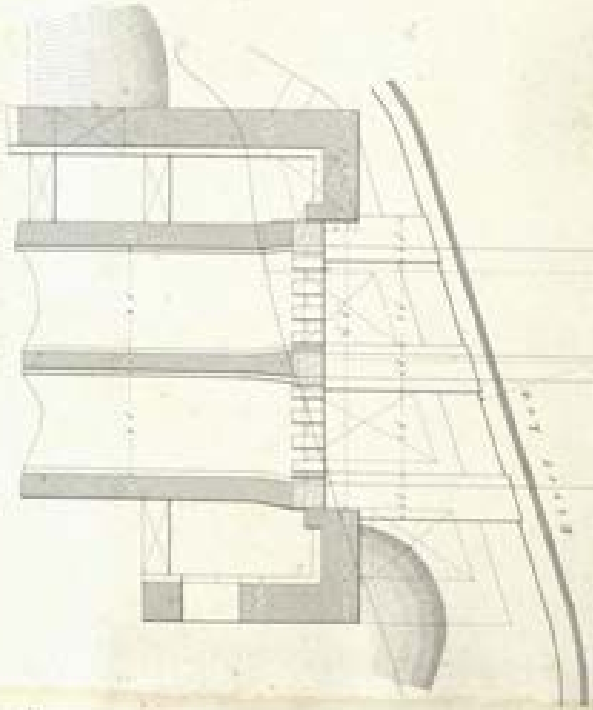
NORTH SIDE.
MIDDLE LEVEL SEWER.

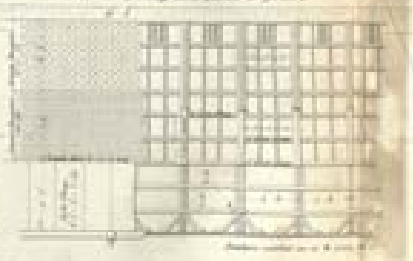


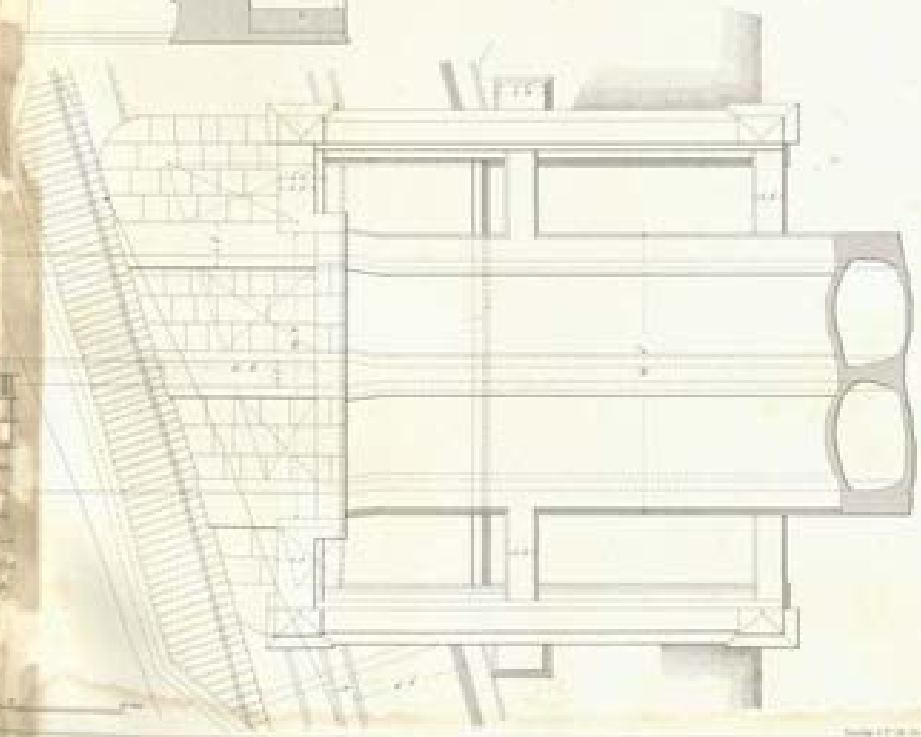
NORTHERN OUTFALL WORKS.

BRIDGE OVER THE RIVER LEA.









MAIN DRAINAGE METROPOLIS.
N°3

A HISTORY OF THE WORKS OF MODERN ENGINEERING 1851.
PLATE 3.

DETAILS OF BRIDGE OVER RIVER LEA.

FIG. 1

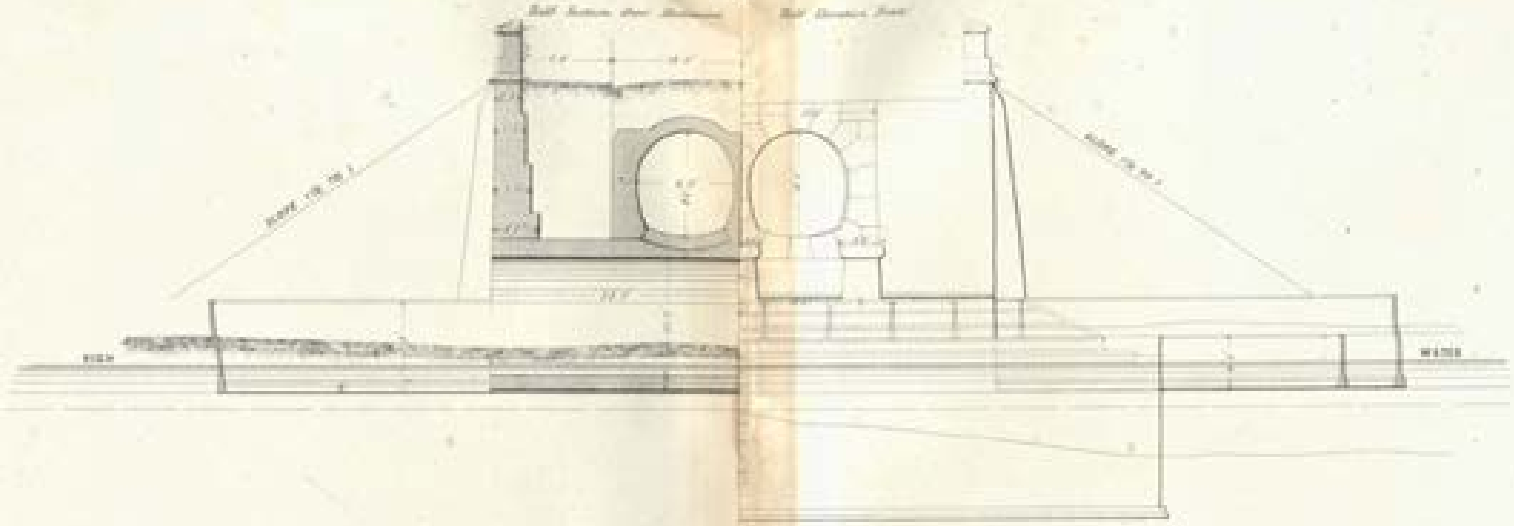


FIG. 2

Cross Section

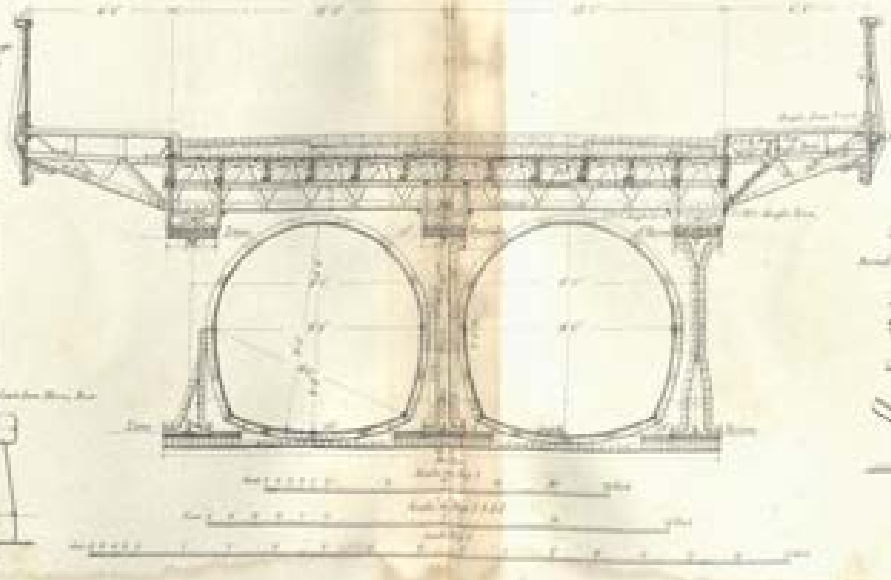


FIG. 3.

Elevation at Towpath on Centre of River, Looking the Piers, the top of cast-iron girders

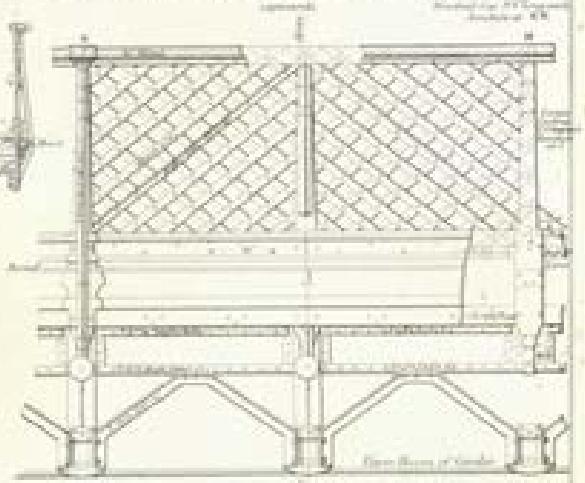


FIG. 5.

Longitudinal Section on line A B

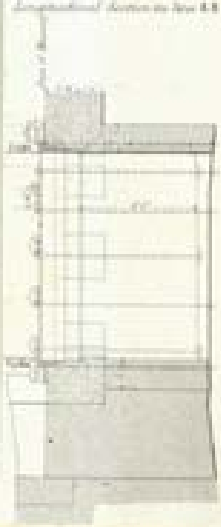
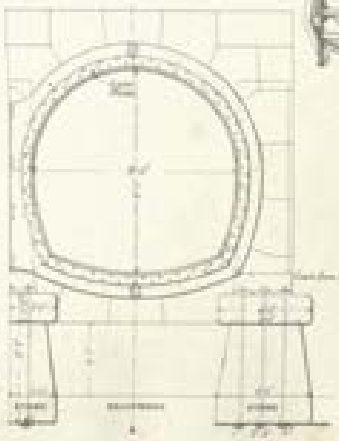


FIG. 6.

Half Front Elevation of Masonry and Iron Castings



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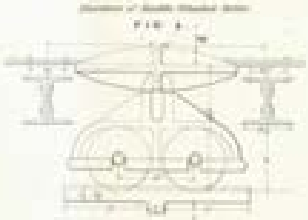
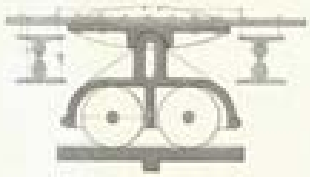
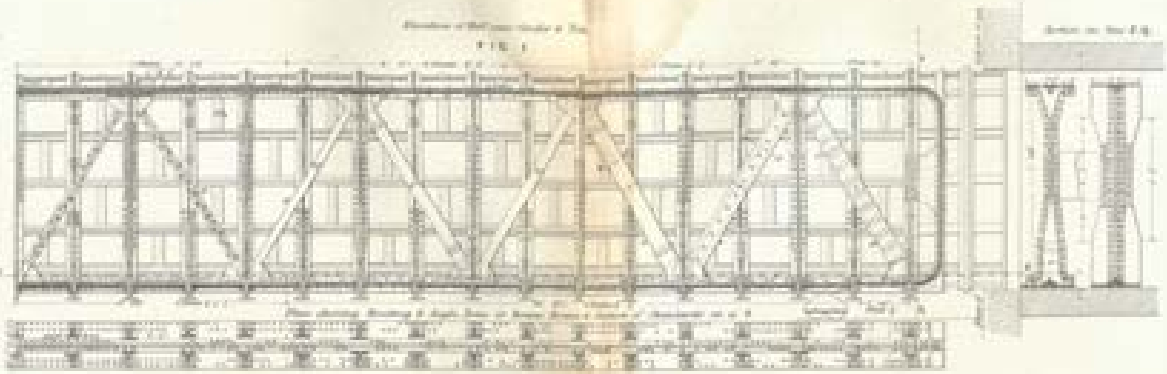
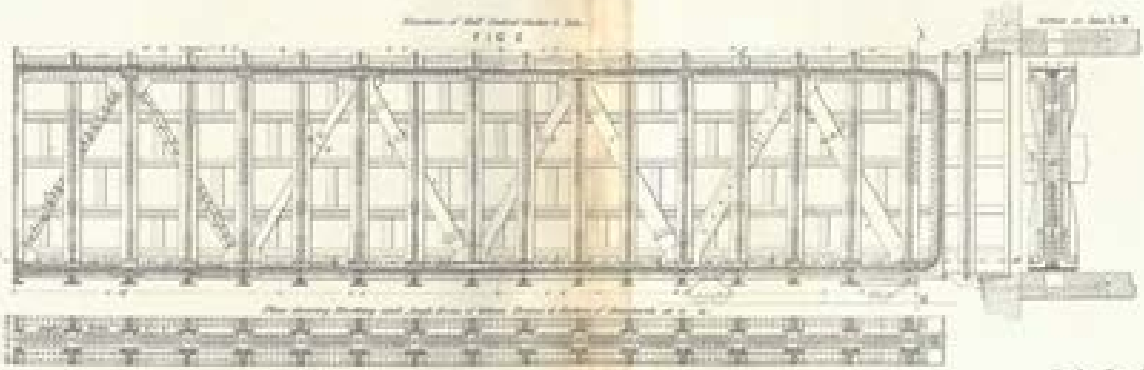
A REVIEW OF THE PROGRESS OF MODERN ENGINEERING 1862.

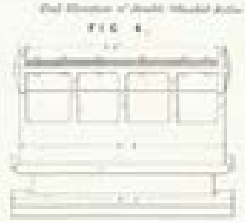
PLATE 6.

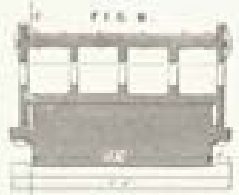


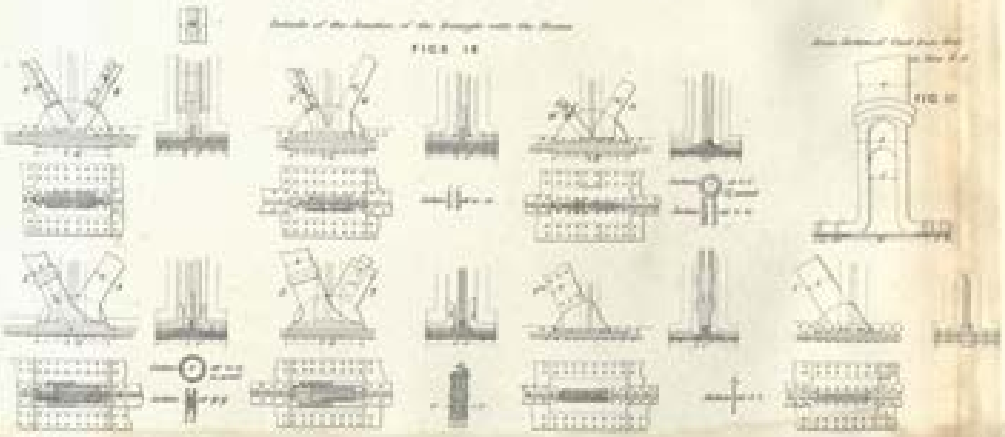


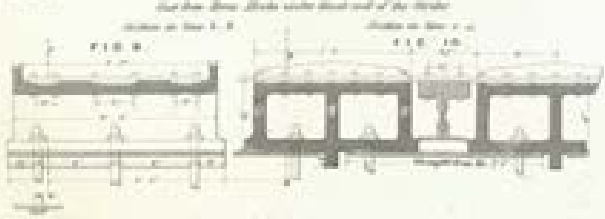






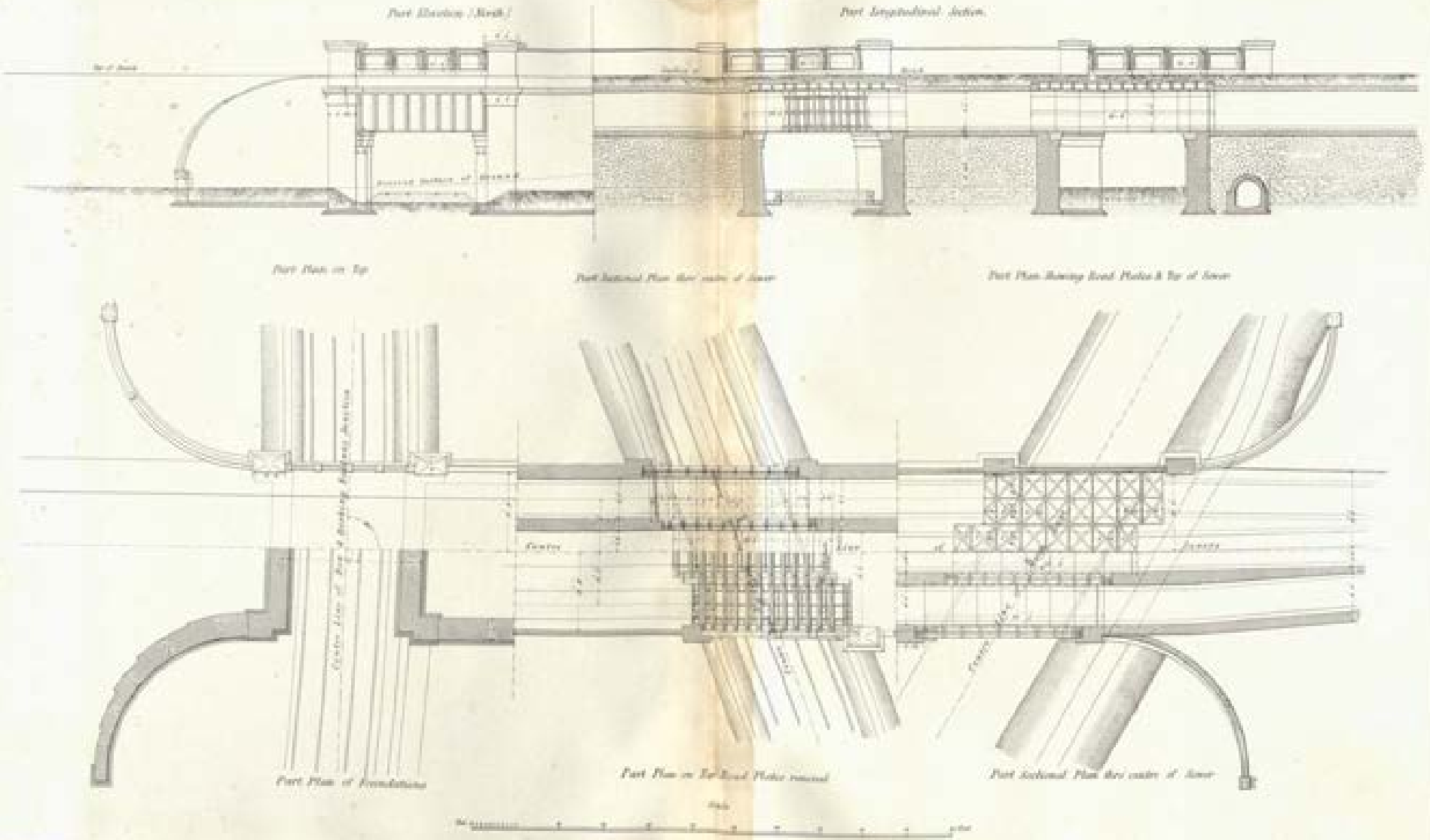






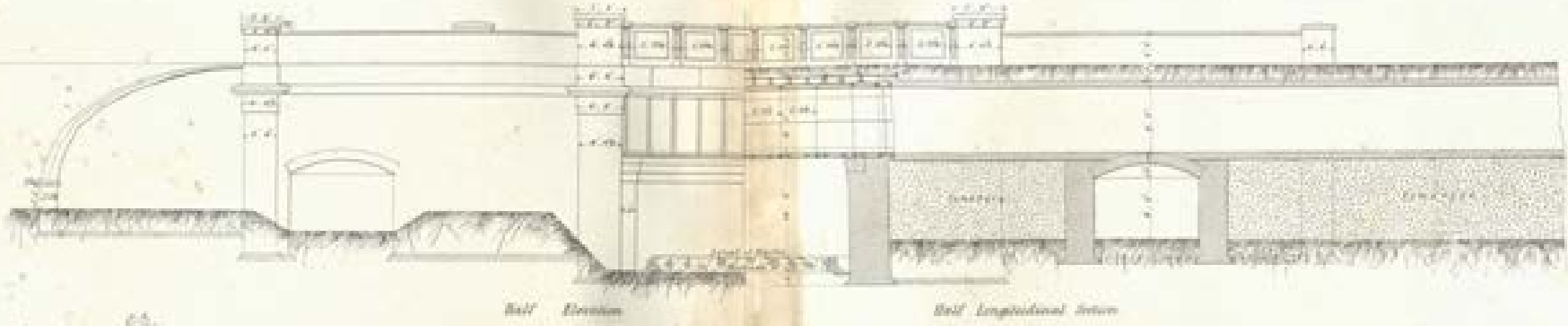
OUTFALL SEWER.

BRIDGE OVER MARSH LANE, NORTH WOOLWICH RAILWAY AND BOW AND BARKING RAILWAY JUNCTION.


Part Elevation (North)
Part Longitudinal Section
Part Plan on Top
Part Sectional Plan thro' centre of Sewer
Part Plan showing Road Platform & Top of Sewer
Part Plan of Foundations
Part Plan on Top Road Platform removed
Part Sectional Plan thro' centre of Sewer

OUTFALL SEWER

BRIDGE OVER THE MAIN LINE OF THE GOR & BARKING RAILWAY



Half Elevation

Half Longitudinal Section

½ Plan on top

½ Plan of foundations

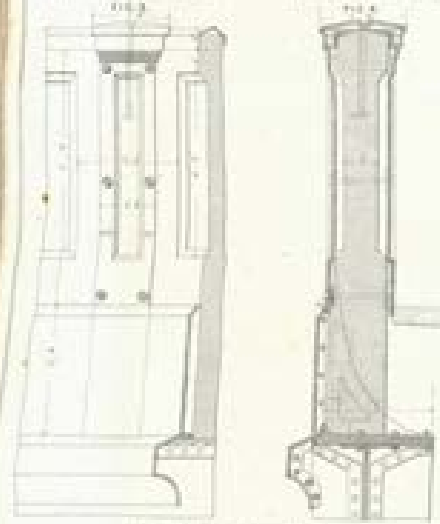
½ Plan Arching Ring Plane

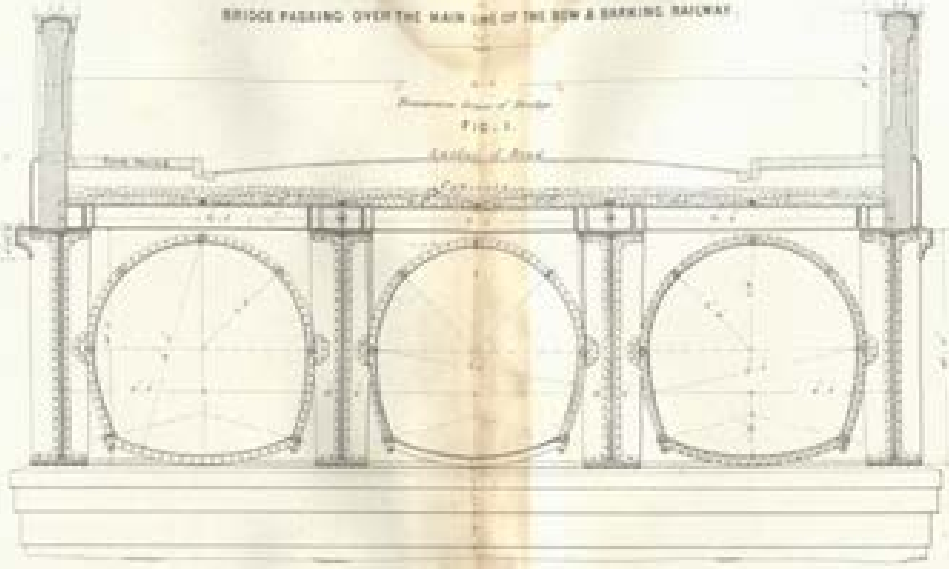
½ Sectional Plan through centre of Sewer

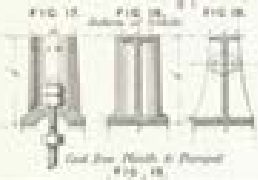
MAIN DRAINAGE METROPOLIS.

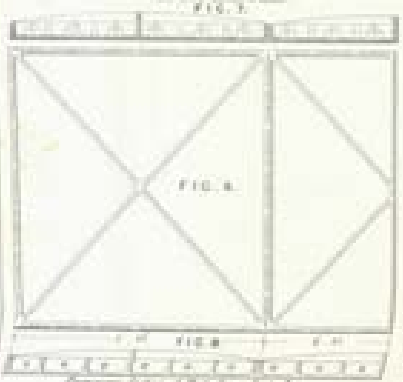
NORTH SIDE OUTFALL SEWER.

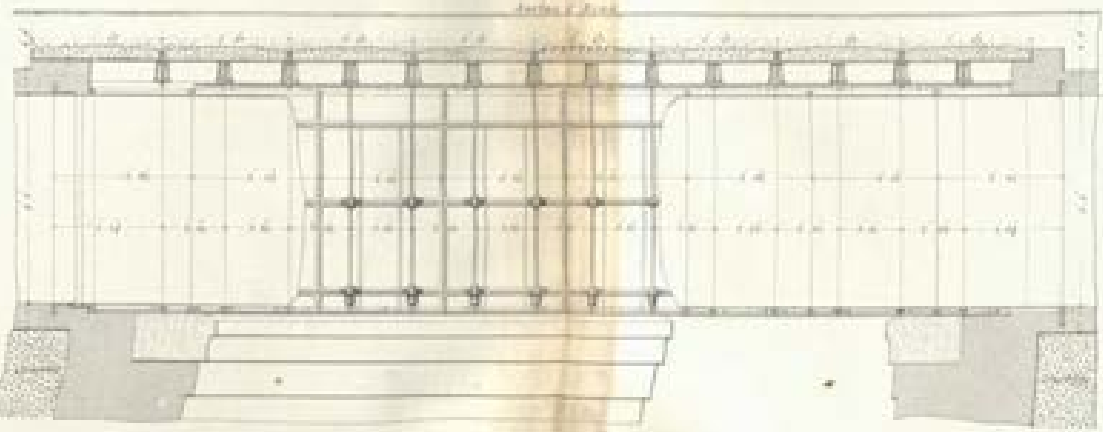
BRIDGE PASSING OVER THE MAIN LINE OF THE NEW & BARKING RAILWAY









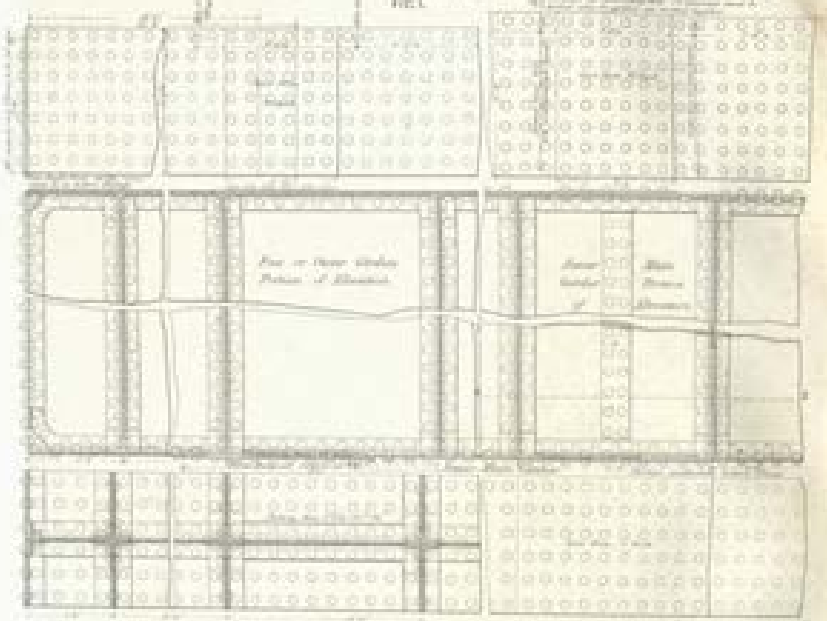


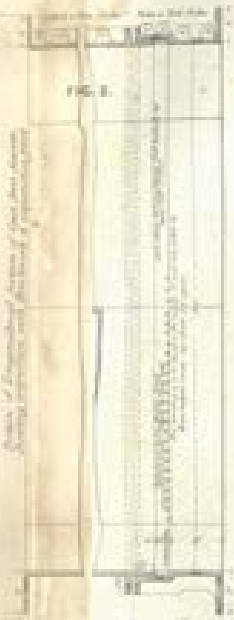
MAIN DRAINAGE METROPOLIS.

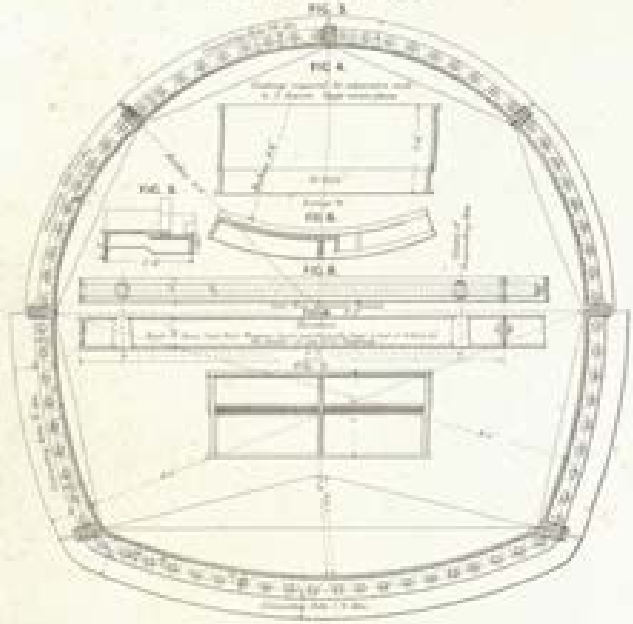
OUTFALL SEWER

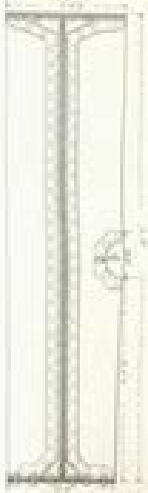
A RECORD OF THE PROGRESS OF MODERN ENGINEERING 1866.

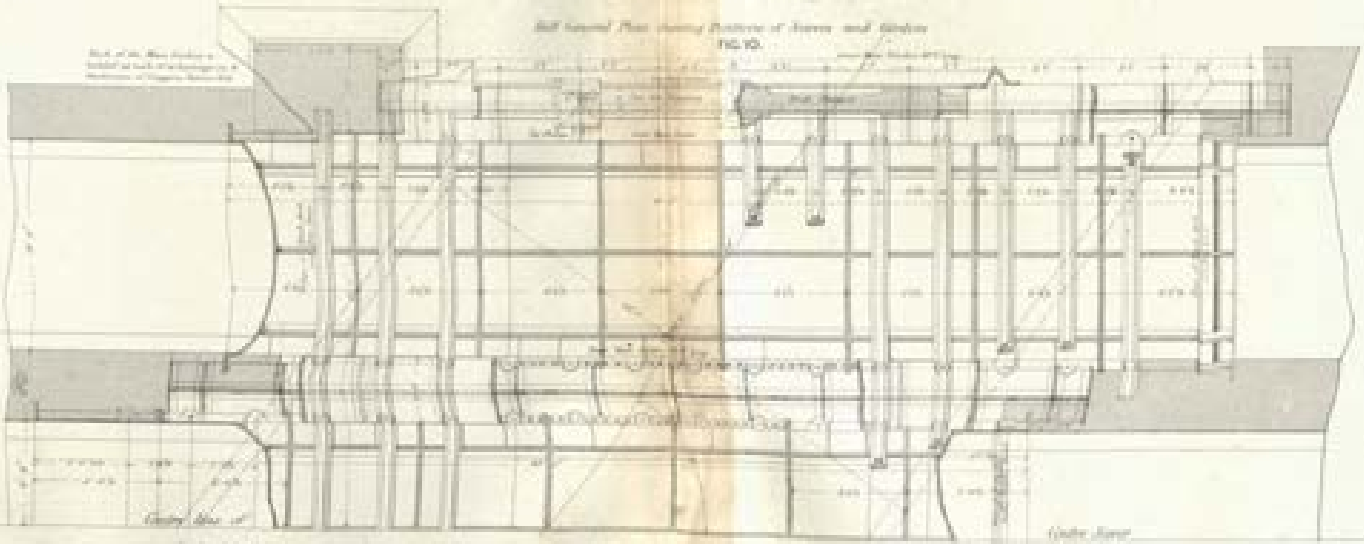
PLATE 90.



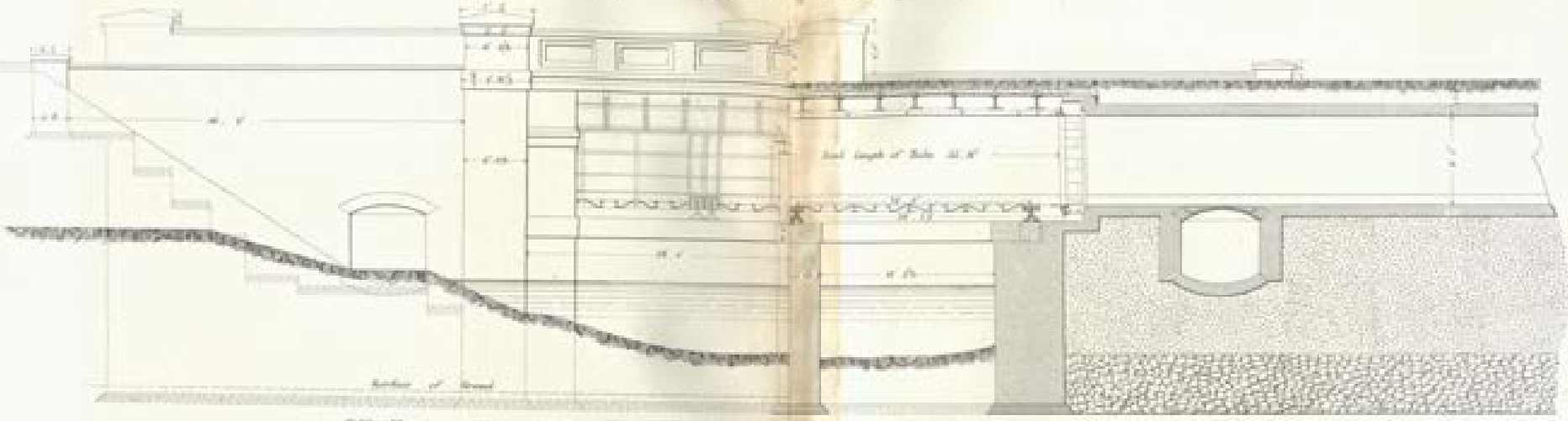








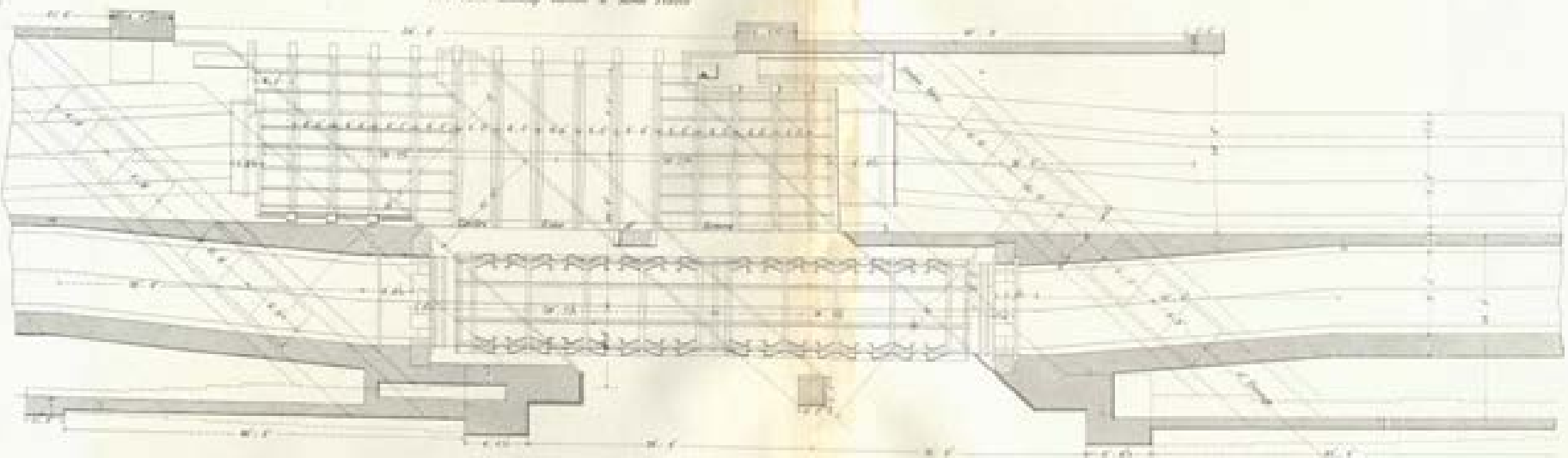
NORTH SIDE OUTFALL SEWER.
BRIDGE OVER EAST LONDON WATERWORKS FEEDER.



Half Elevation

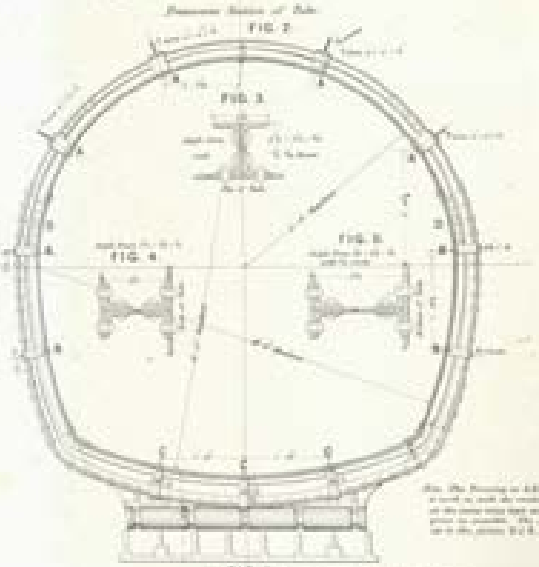
Half Longitudinal Section

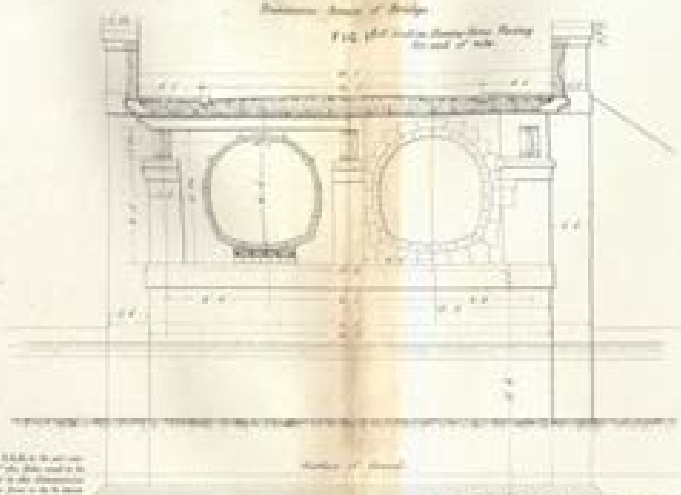
Half Plan showing Centres & Road Plates

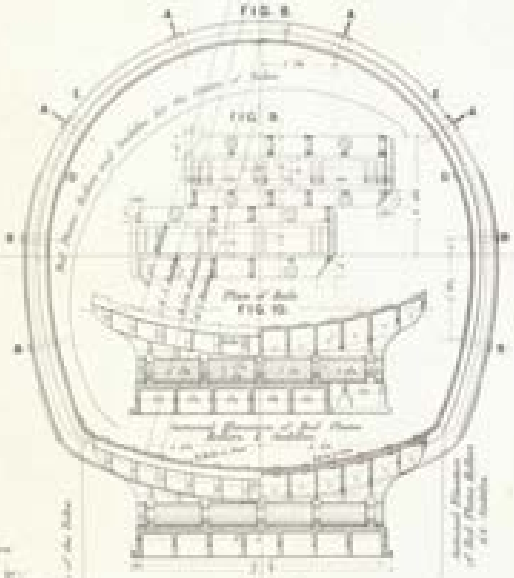


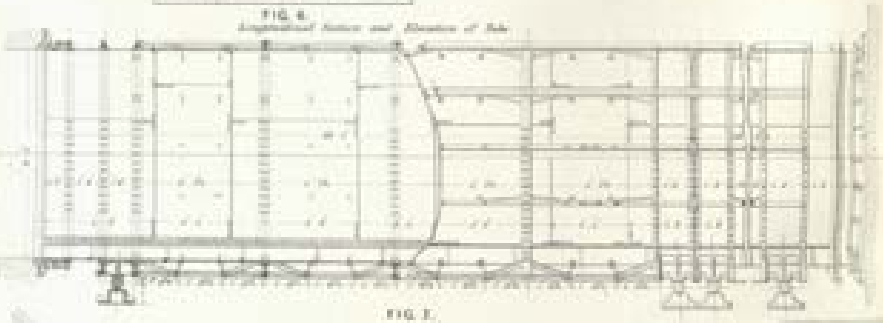
Half Plan showing Side

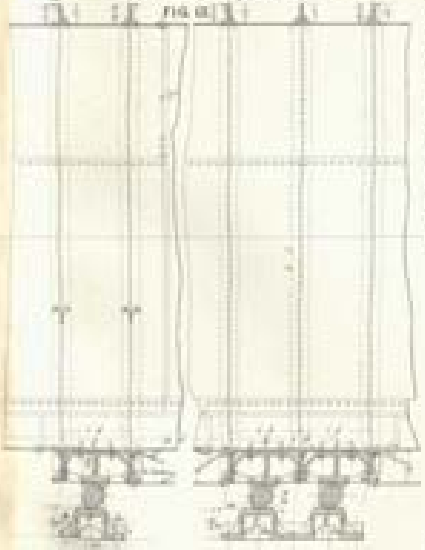
DETAILS OF BRIDGE OVER EAST LONDON WATERWORKS FEEDER.

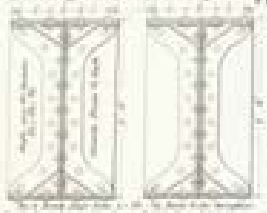


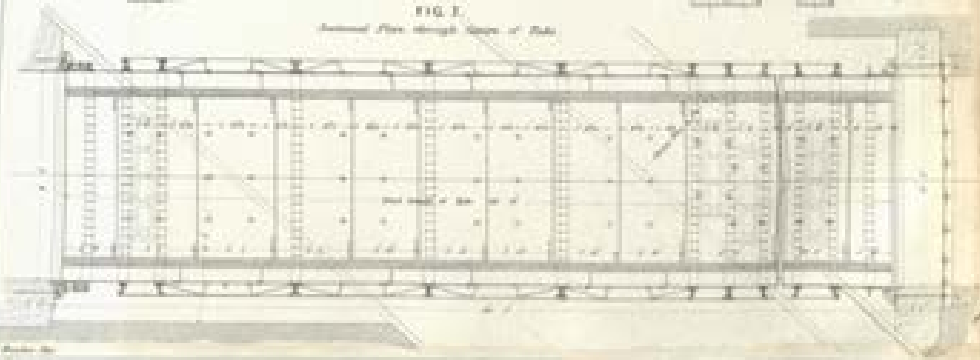


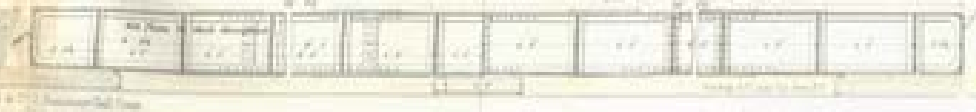










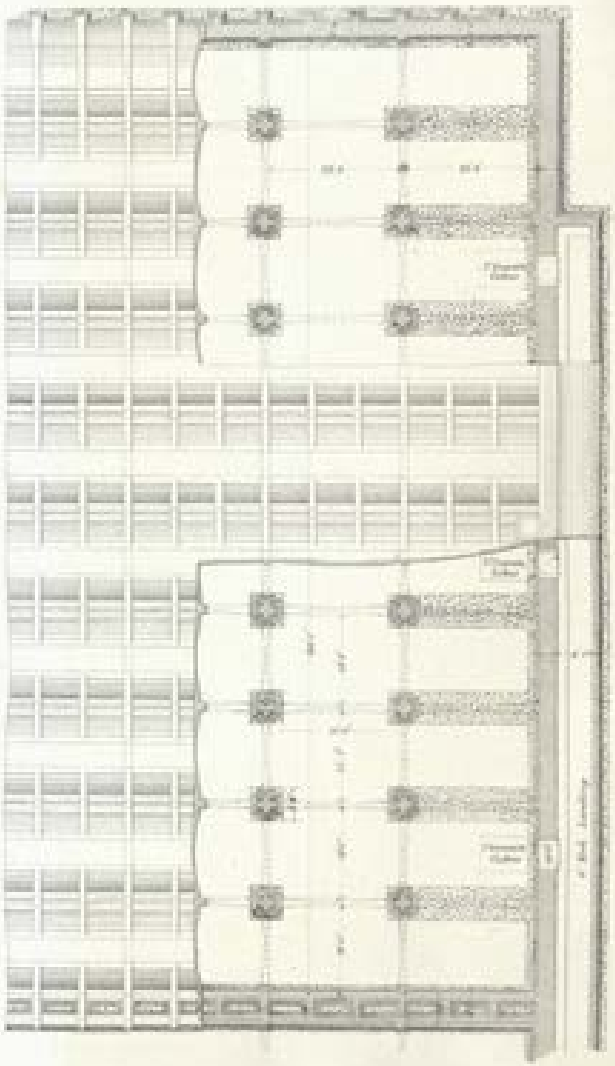


London: Published at the Offices of the Engineer, Gate Street.

MAIN DRAINAGE METROPOLIS.

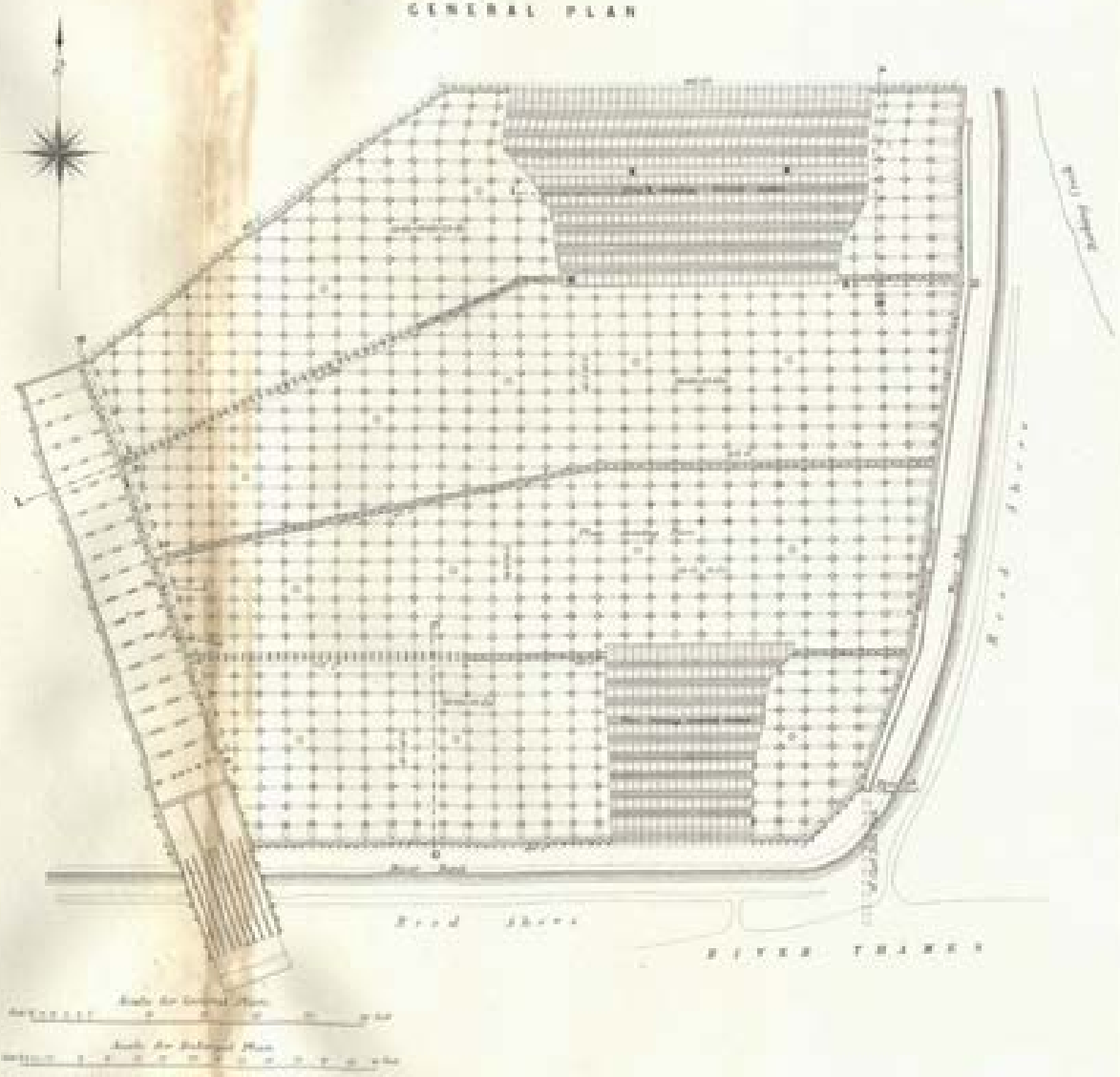
No 11.

PART ENLARGED PLAN



RESERVOIR

GENERAL PLAN



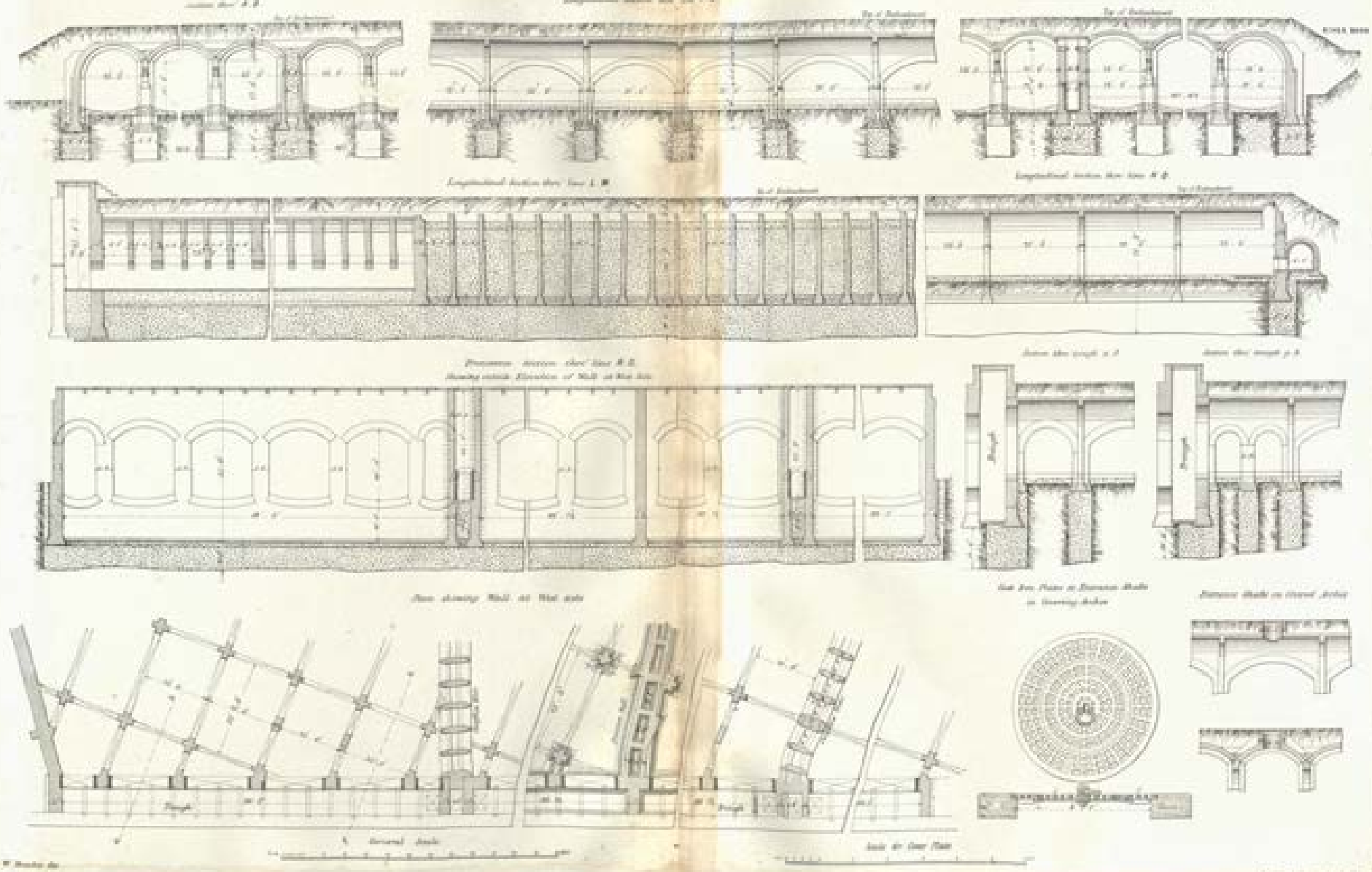
MAIN DRAINAGE METROPOLIS.

W. H.

DETAILS OF RESERVOIR.

A RECORD OF THE PROGRESS OF MODERN ENGINEERING. 1865.

PLATE M.



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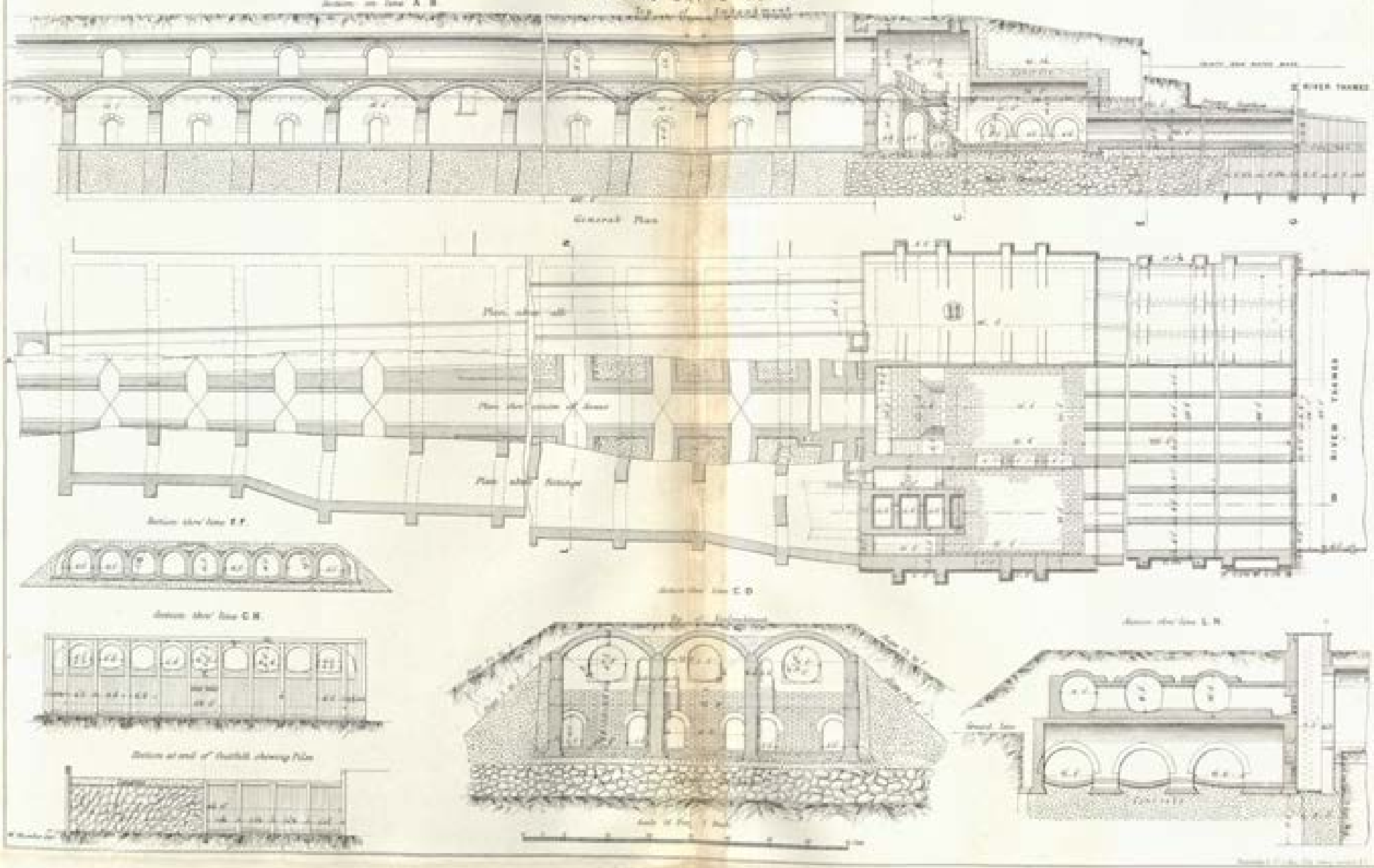
MAIN DRAINAGE METROPOLIS.

OUTFALL SEWER.

TUMBLING BAY & OUTLET



MAIN DRAINAGE METROPOLIS.

Nº 16.

A REVISED OF THE WORKS OF MESSRS. ENGLEHEART & PAGE.

PLATE 16.

PENSTOCK FOR FLUSHING CULVERT.

NORTHERN OUTFALL SEWER.

RESERVOIR.

OUTFALL PENSTOCK.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

FIG. 9.

FIG. 10.

FIG. 11.

FIG. 12.

FIG. 13.

FIG. 14.

FIG. 15.

FIG. 16.

FIG. 17.

FIG. 18.

FIG. 19.

FIG. 20.

FIG. 21.

FIG. 22.

FIG. 23.

FIG. 24.

FIG. 25.

FIG. 26.

FIG. 27.

FIG. 28.

FIG. 29.

FIG. 30.

MAIN DRAINAGE METROPOLIS.

SOUTH SIDE

LOW LEVEL SEWER BERMONDSEY BRANCH

A RECORD OF THE PROGRESS OF MODERN ENGINEERING 1865.

PLATE 17.

JUNCTION WITH THE DUFFIELD SEWER EPE ROAD

JUNCTION WITH THE EARL SEWER, DEPTFORD LOWER ROAD

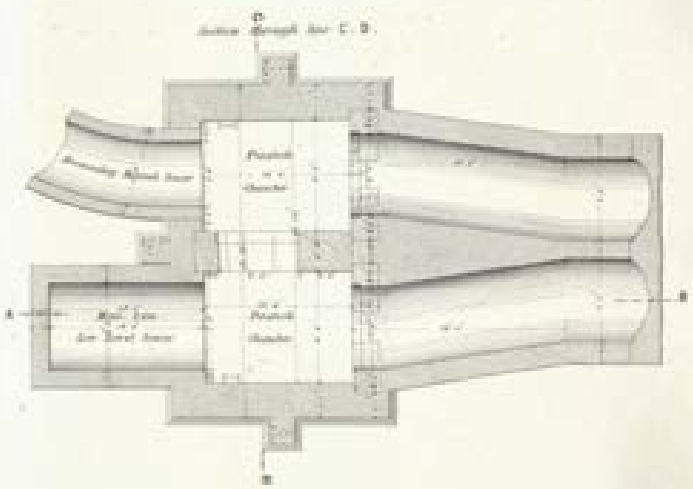
MAIN DRAINAGE METROPOLIS.

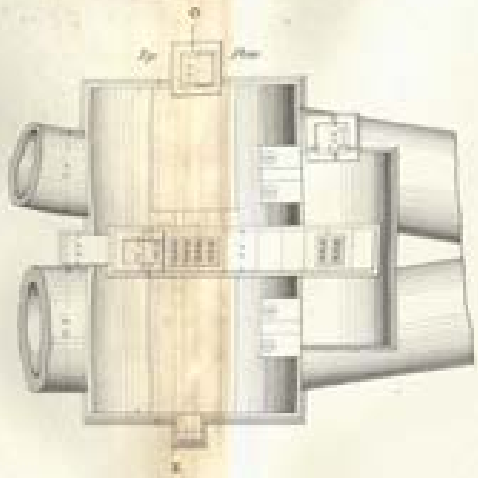
No IX.

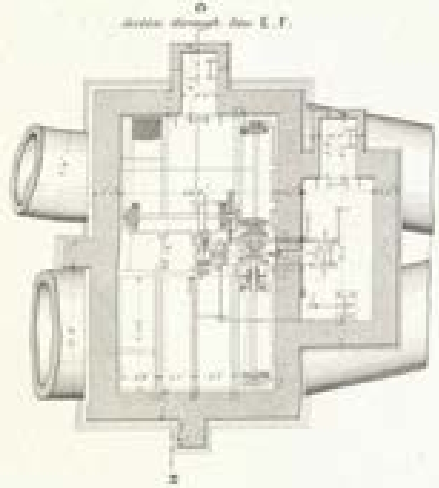
SOUTH SIDE.

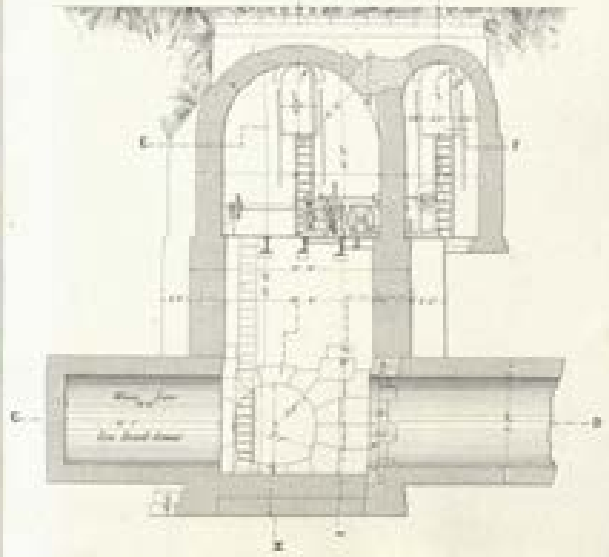
LOW LEVEL SEWER HERNONDSEY BRANCH

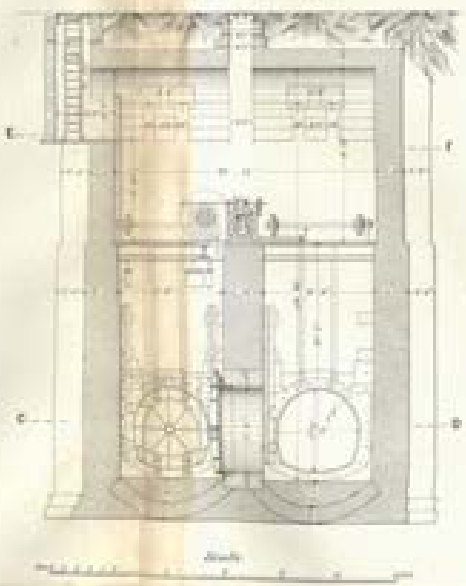
JUNCTION WITH MAIN LINE.

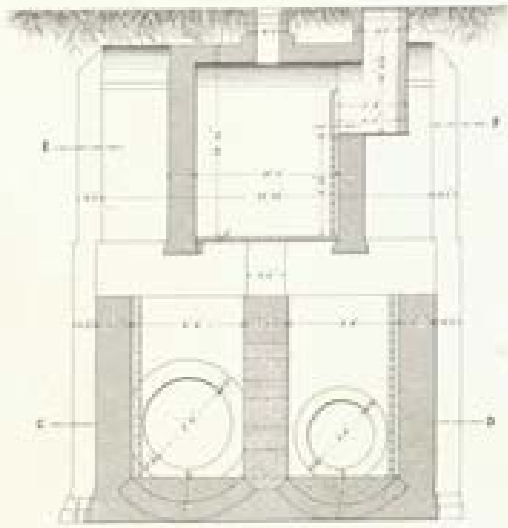












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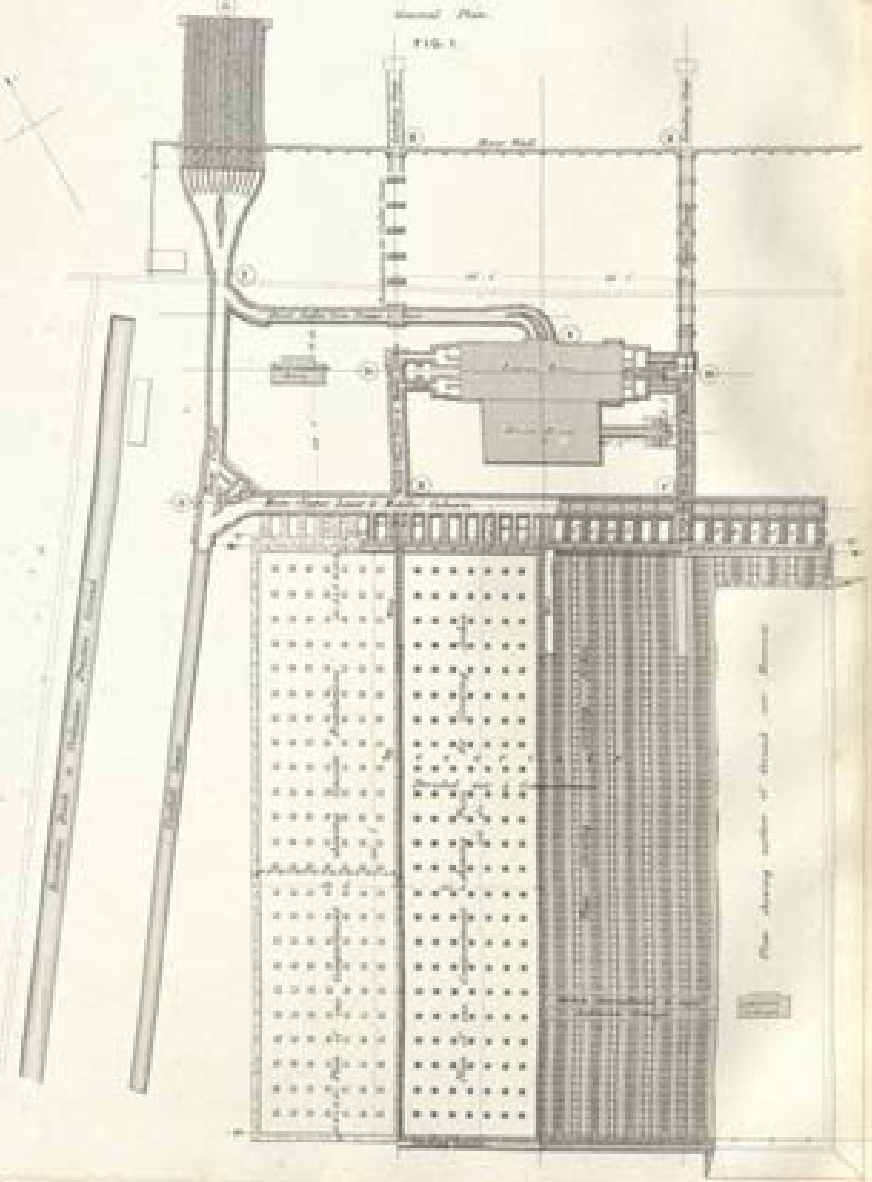
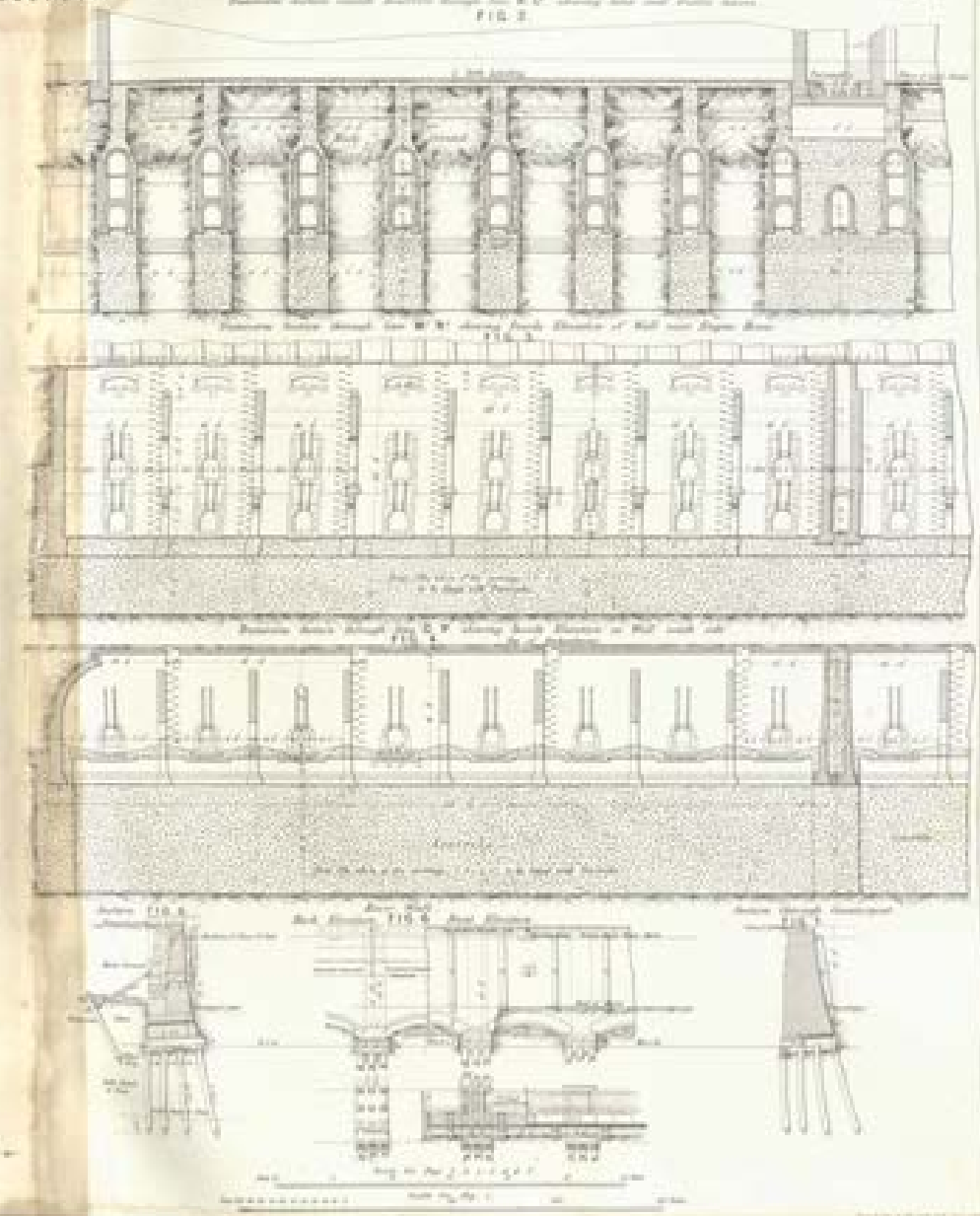
MAIN DRAINAGE METROPOLIS.

SOUTHERN OUTFALL WORKS
RESERVOIR

A RECORD OF THE PROGRESS OF MODERN ENGINEERING 1862
PLATE 19





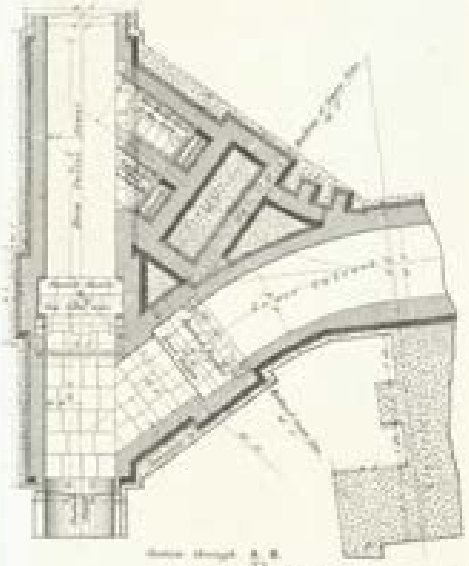
MAIN DRAINAGE METROPOLIS.

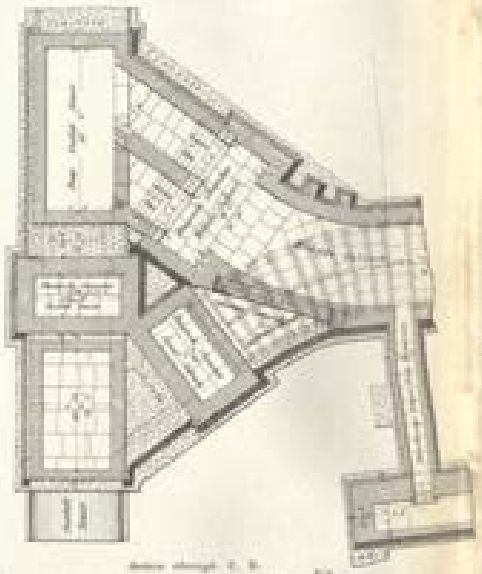
SOUTHERN OUTFALL WORKS.

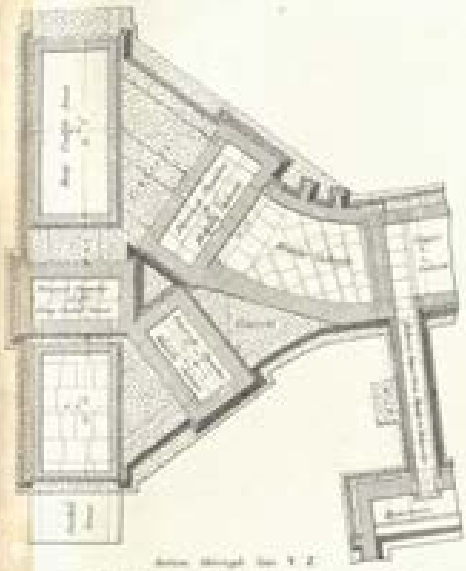
SEWER.

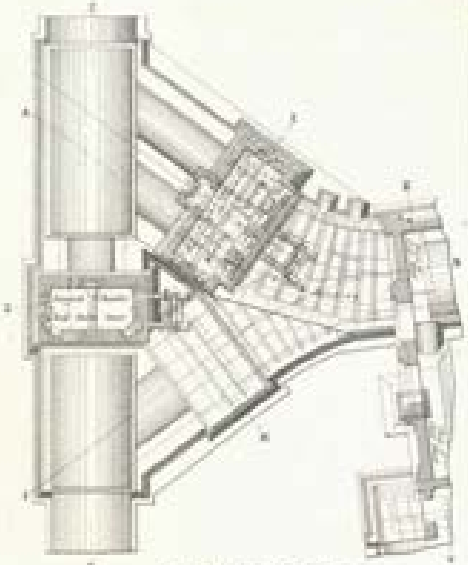
A HISTORY OF THE PROGRESS OF MODERN ENGINEERING &c.

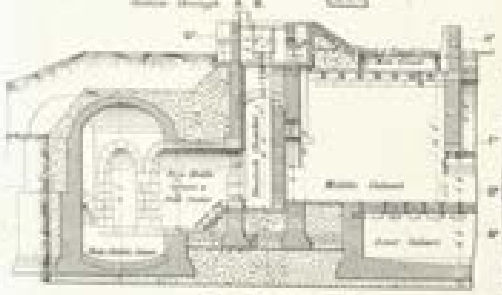
PLATE 20.

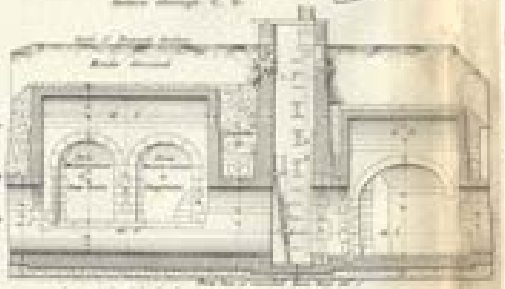


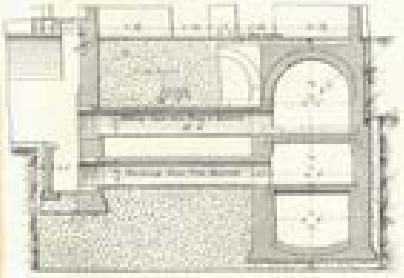


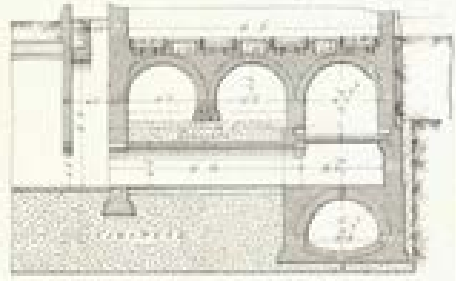


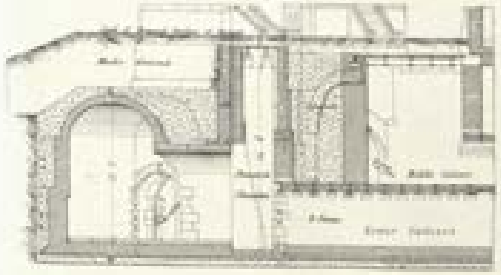


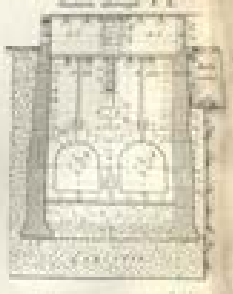


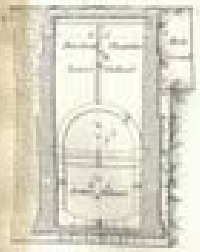


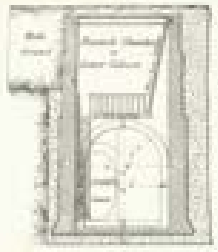


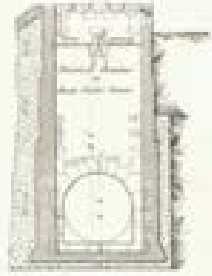




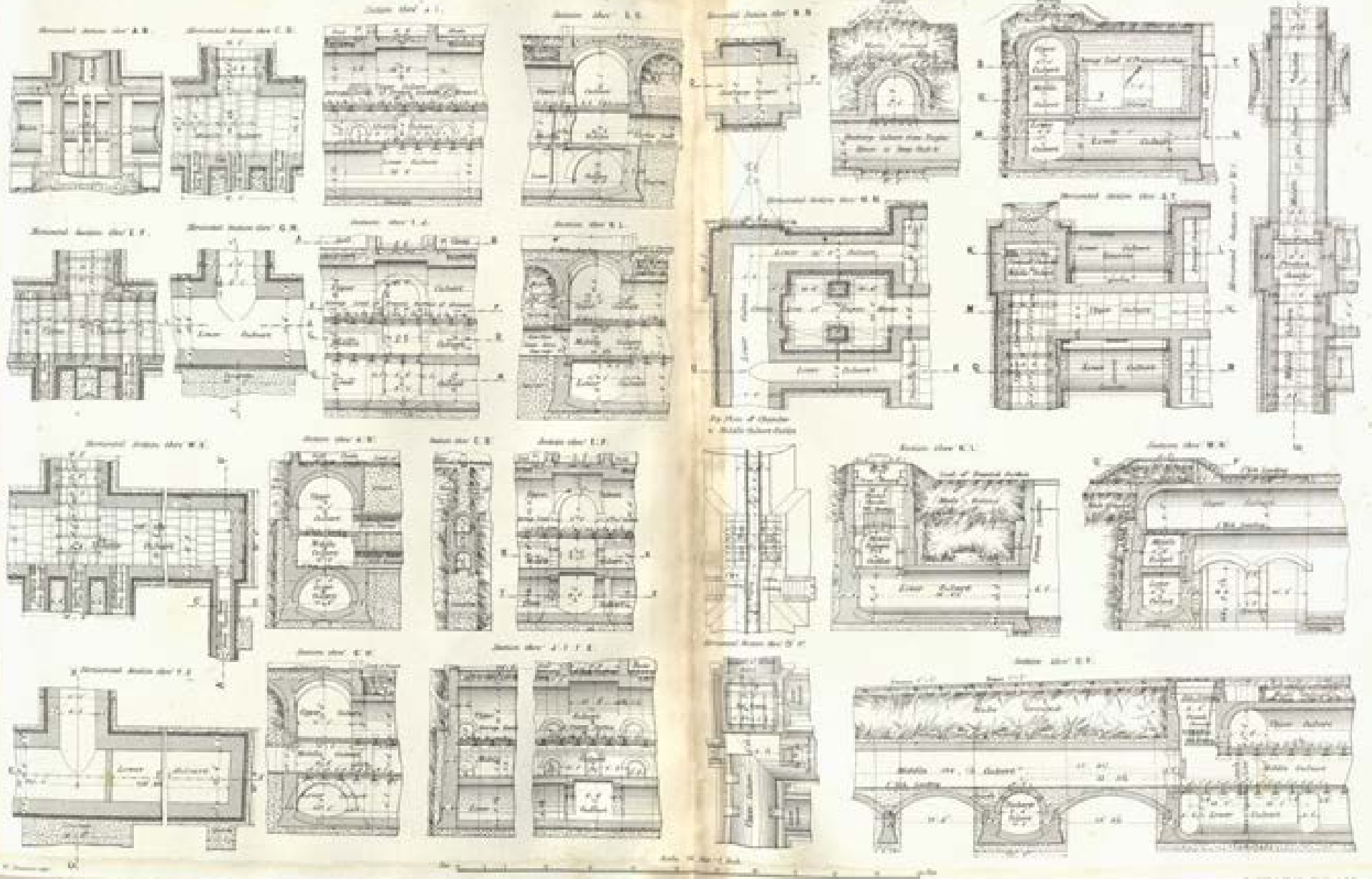








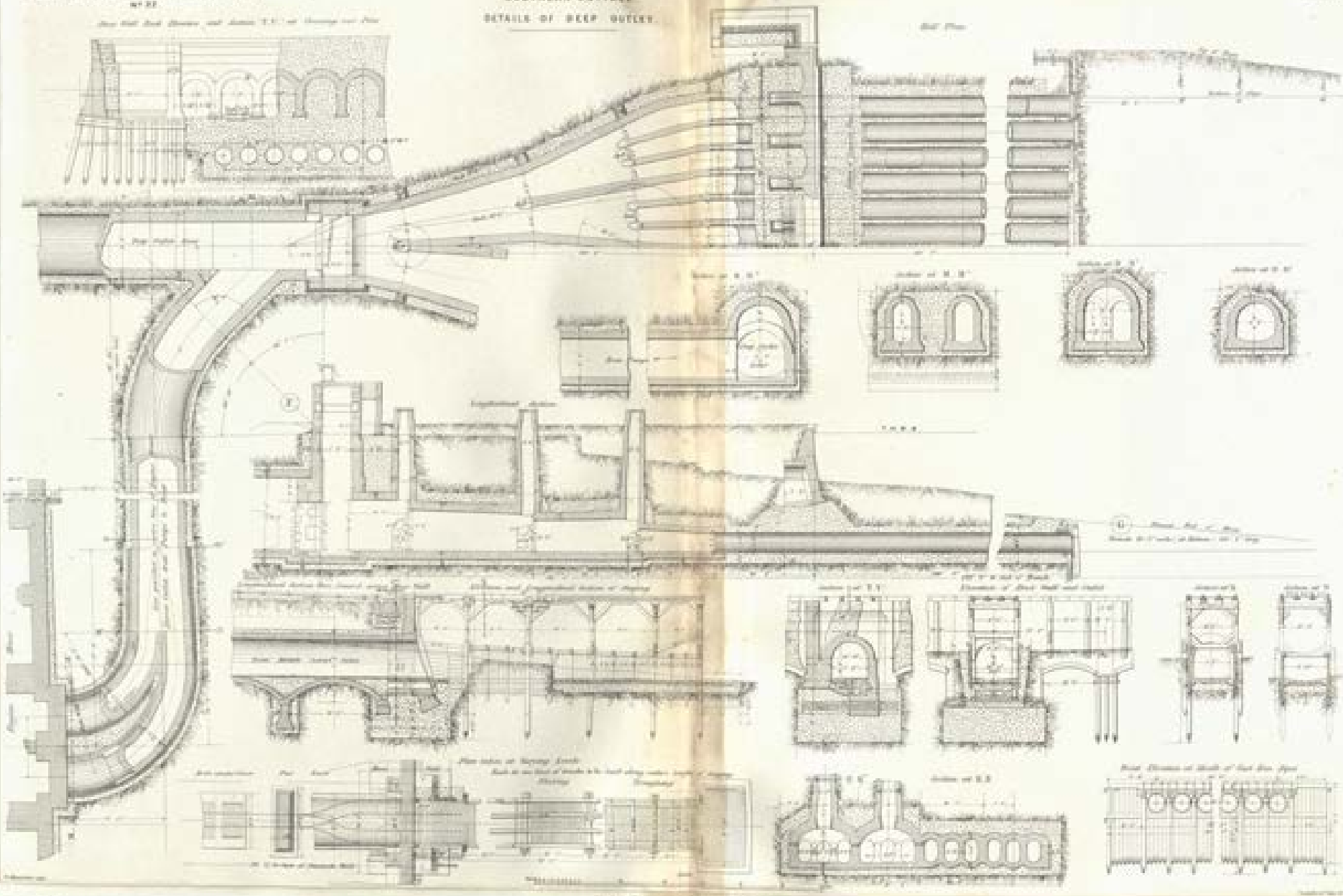
SOUTHERN OUTFALL WORKS
SEWERS



MAIN DRAINAGE METROPOLIS.

SOUTHERN OUTFALL.

DETAILS OF DEEP OUTLET.



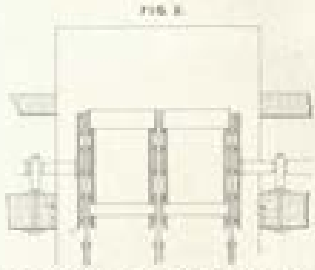
SOUTHERN OUTFALL WORKS.

DETAILS OF TILT, HOIST & PENSTOCK.

FIG. 1.

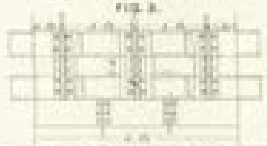
Side Elevation of Chamber & Arches of Arrans with Tilts.

FIG. 2.



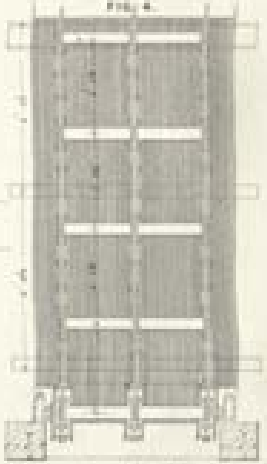
Elevation of Open Arrans with Shafts Hoists & Carriages

FIG. 3.



Front Elevation of Tilts Hoist showing gearing

FIG. 4.



Elevation of Arrans showing Arrans & Penstocks

FIG. 5.

Plan of Lower Arrans

FIG. 6.

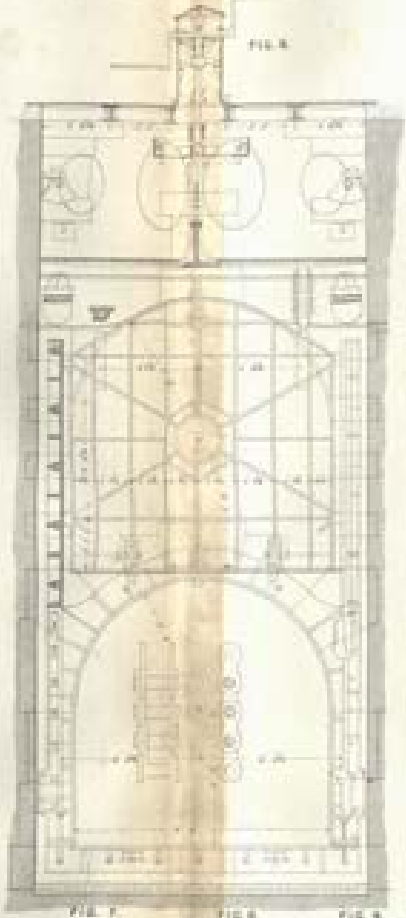


FIG. 7.

Details of Girder for supporting the Tilting Arrans

FIG. 8.

FIG. 9.

Arrangements of the Compressed Cylinder for working the Penstocks

FIG. 10.

FIG. 11.

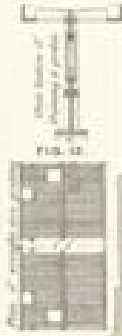


FIG. 12.

FIG. 13.

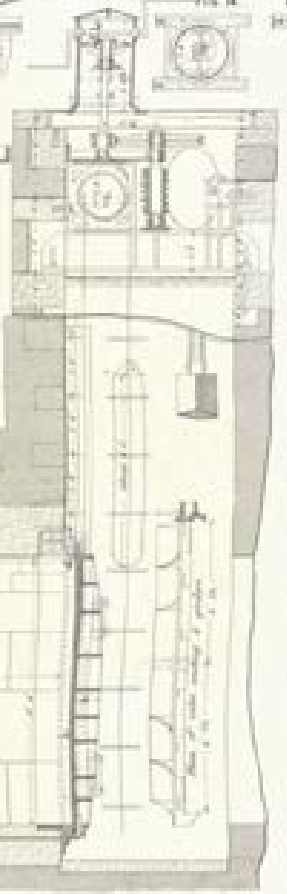


FIG. 14.

FIG. 15.

FIG. 16.

FIG. 17.

FIG. 18.

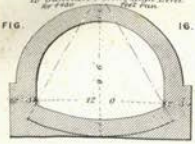
Scale for Figs. 1. 2.

Scale for Figs. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18.

Scale for Figs. 19. 20.

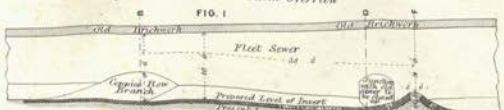
MAIN DRAINAGE METROPOLIS.

FIG. 16. Section of Sewer Old Ford Rd. to Junction with High Level for 440 feet Fall.



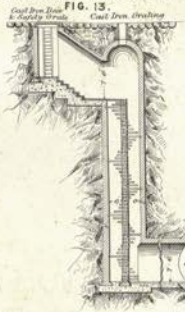
Longitudinal Section & Storm Overflow

FIG. 1



Plan & Section of Side Entrance

FIG. 13.



Plan & Section of Ventilating Shaft

FIG. 13.

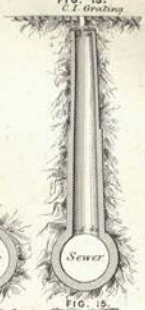


FIG. 17. Section of Branch Sewer at West Ham

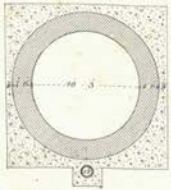


FIG. 2. Plan

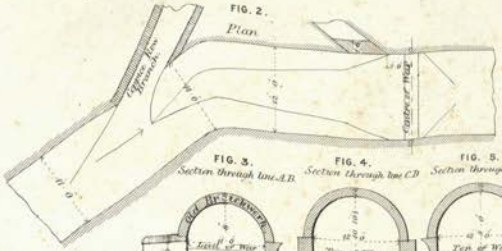


FIG. 3. Section through line A.B.

FIG. 4. Section through line C.D

FIG. 5. Section through line E.F

FIG. 14.

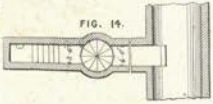


FIG. 15.

FIG. 8.

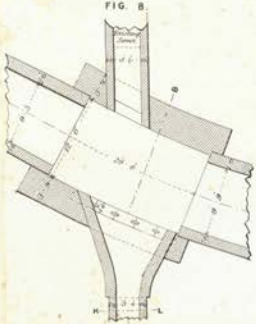
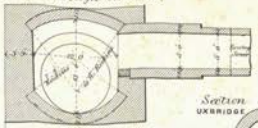


FIG. 6. Section through line A.B.



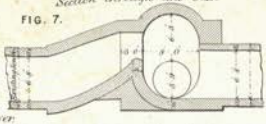
Section through line K.L.

FIG. 9.

Section of Sewer UXBRIDGE ROAD. for 460 ft. run.

FIG. 18.

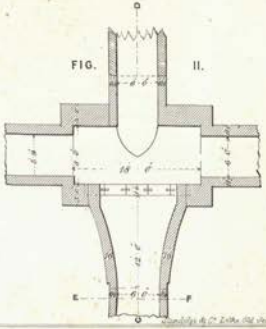
FIG. 7. Section through line C.D.



Section through E.F

FIG. 10.

FIG. 11.



Scale ½ inch to the foot for Figs. 1 to 11. 50 Feet.

Scale ¼ for Figs. 12. 13. 14. 15. 50 Feet.

Scale ⅛ inch to the foot for Figs. 16. 17. 18. 50 Feet.

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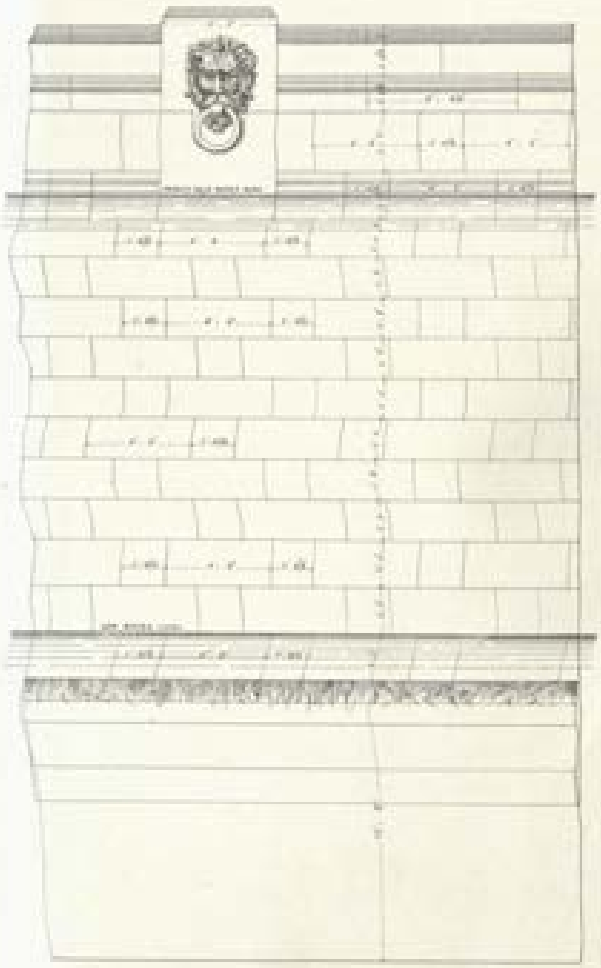
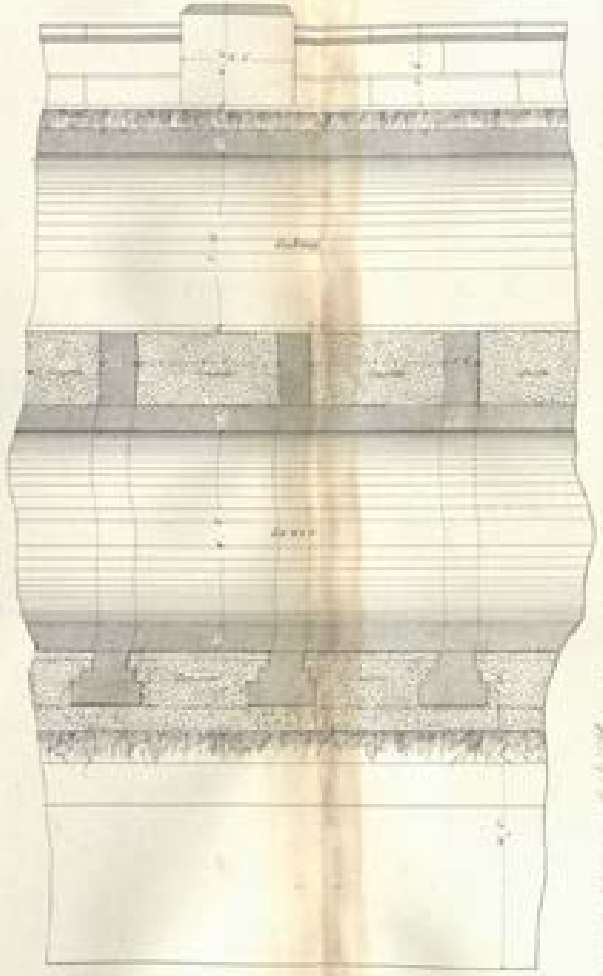
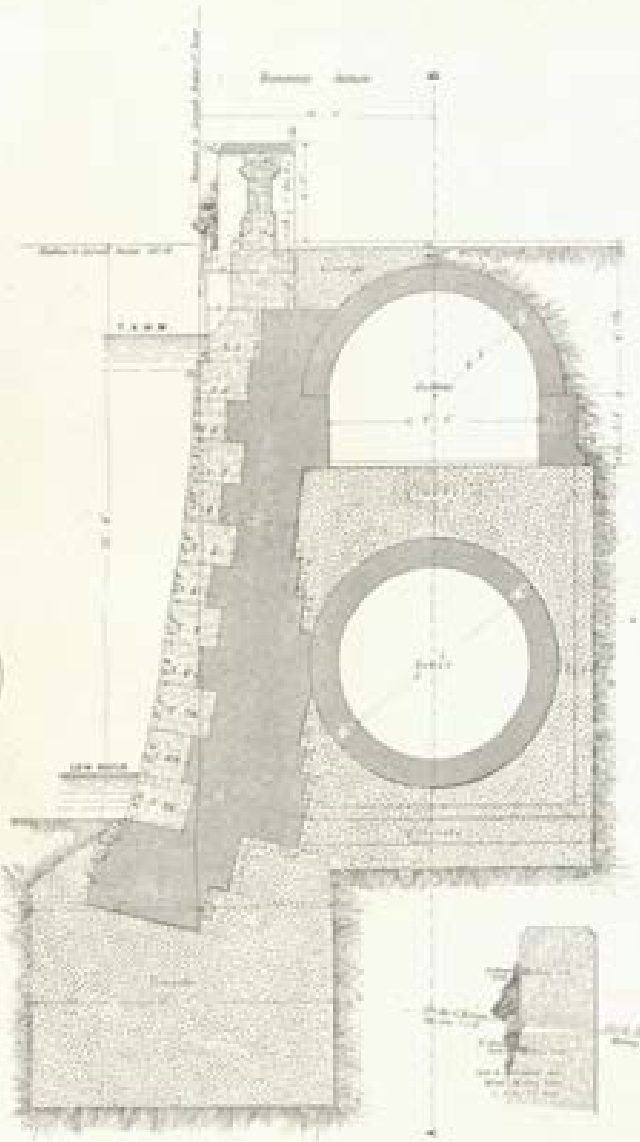
DETAILS OF RIVER WALL







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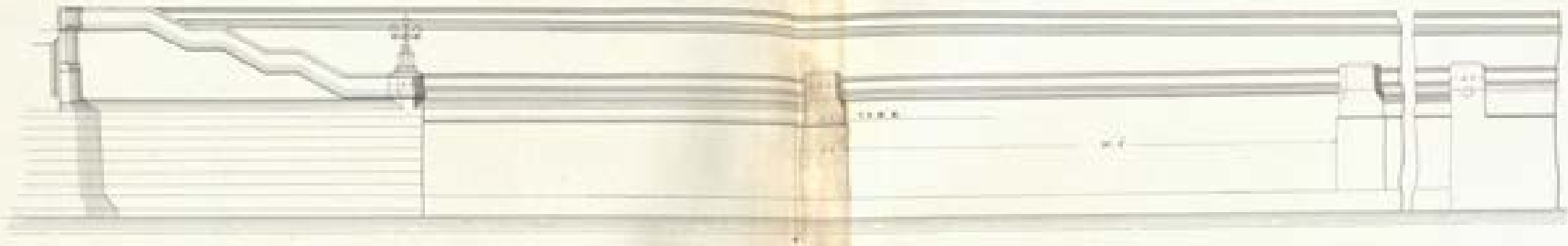
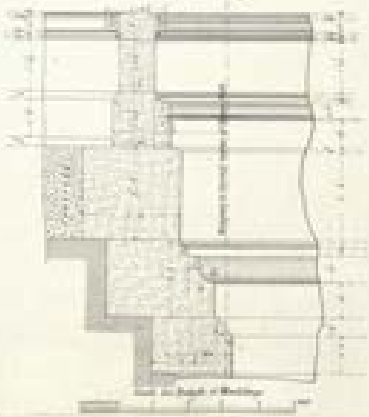
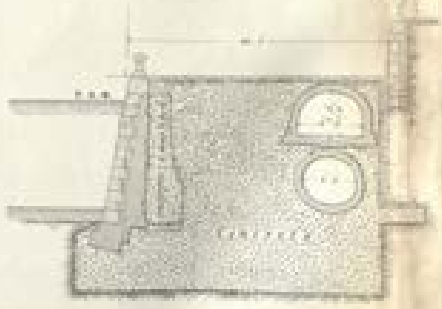
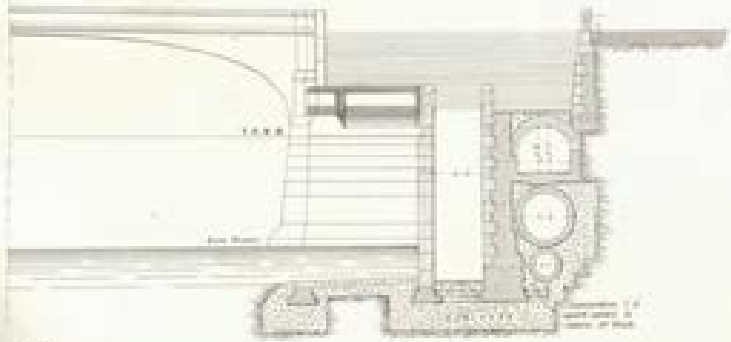
No 1

STEAM BOAT LANDING PIER WESTMINSTER BRIDGE









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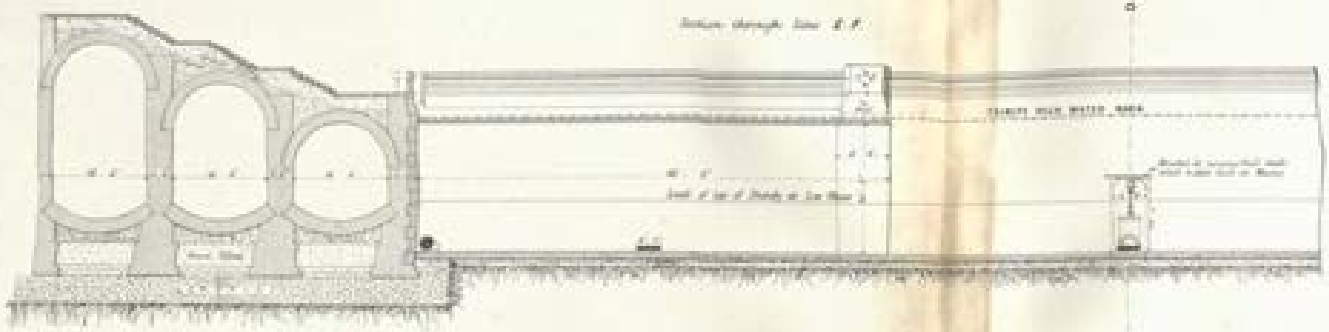
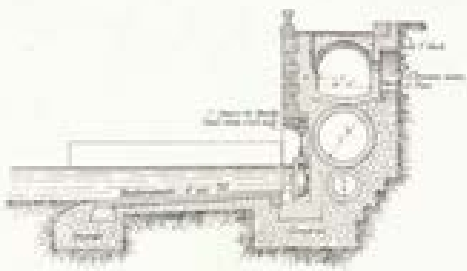
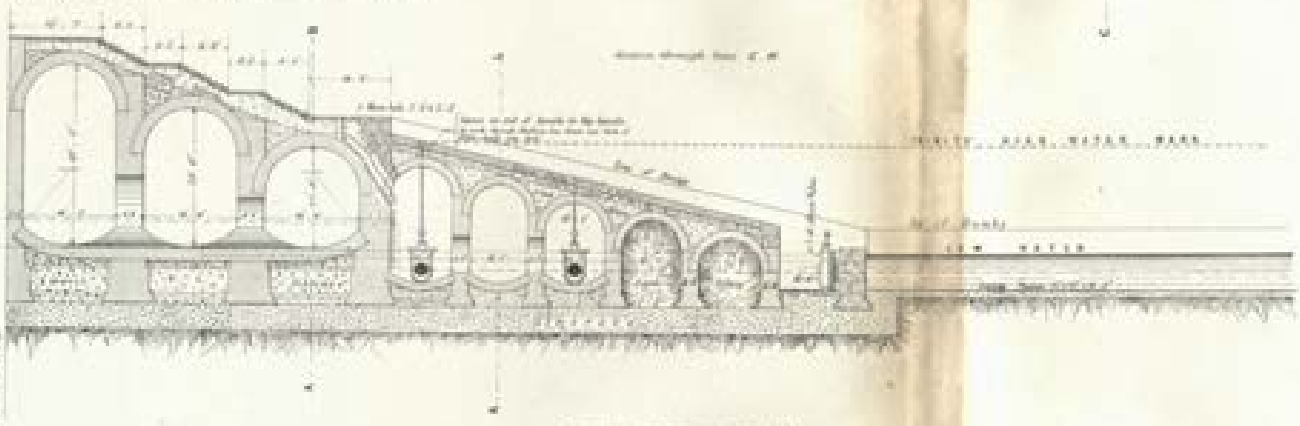
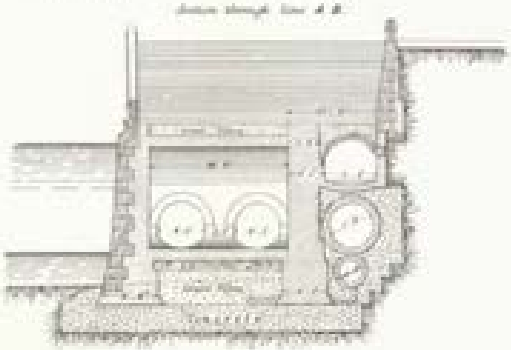
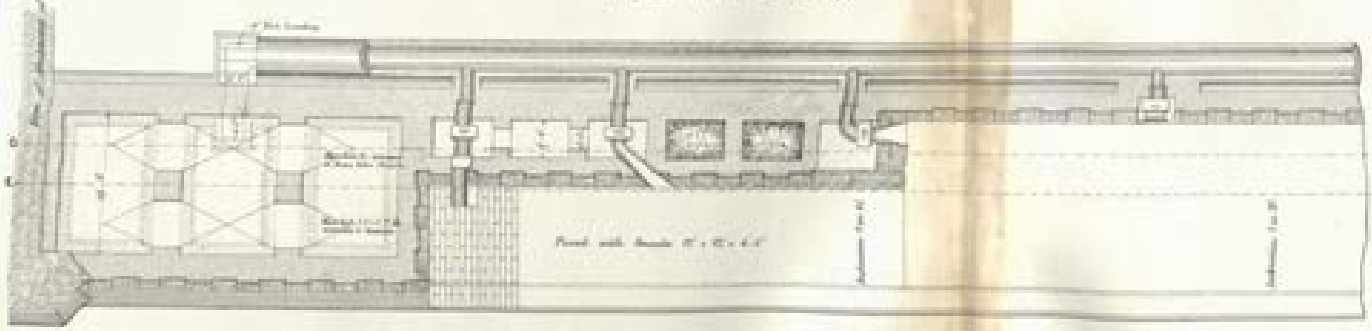
STEAMBOAT LANDING PIER, WESTMINSTER BRIDGE.

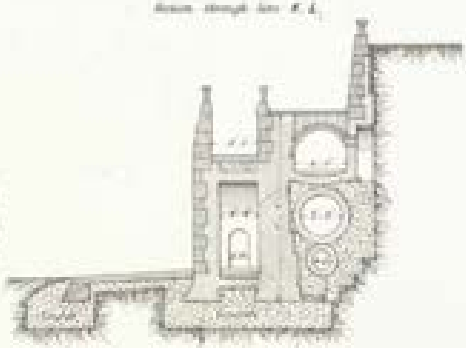












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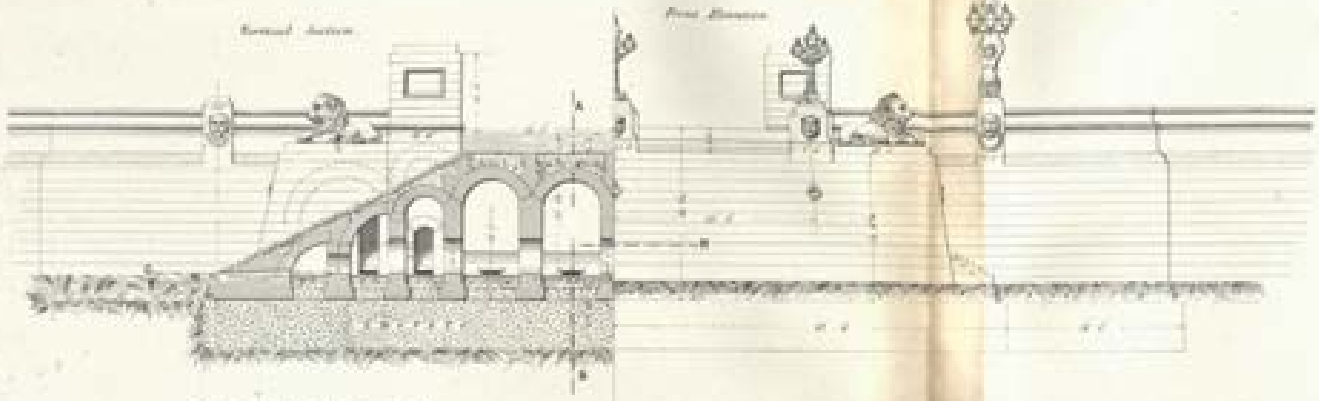
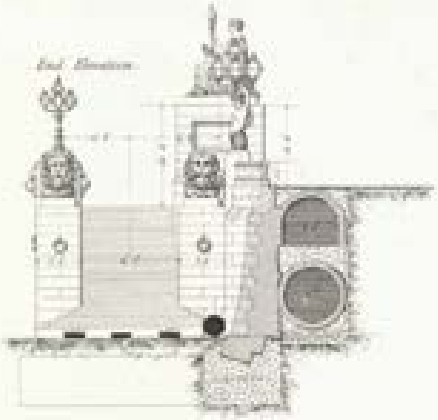
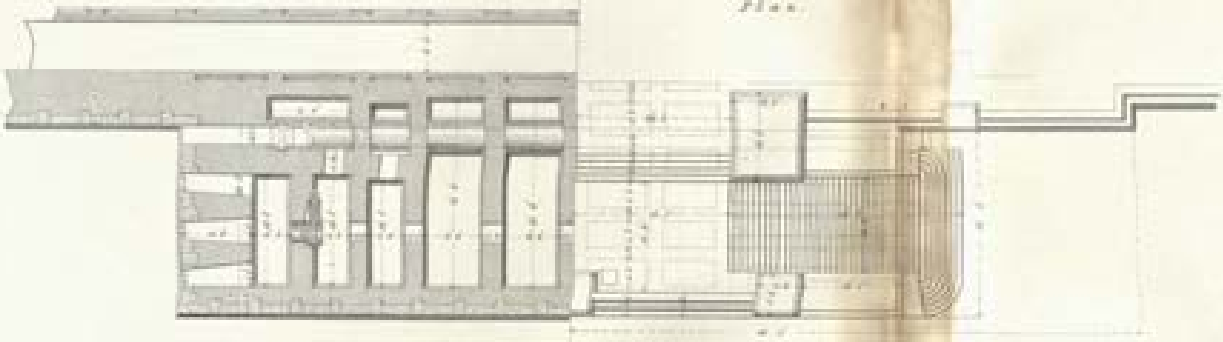
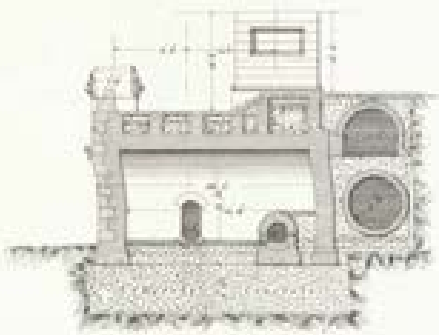
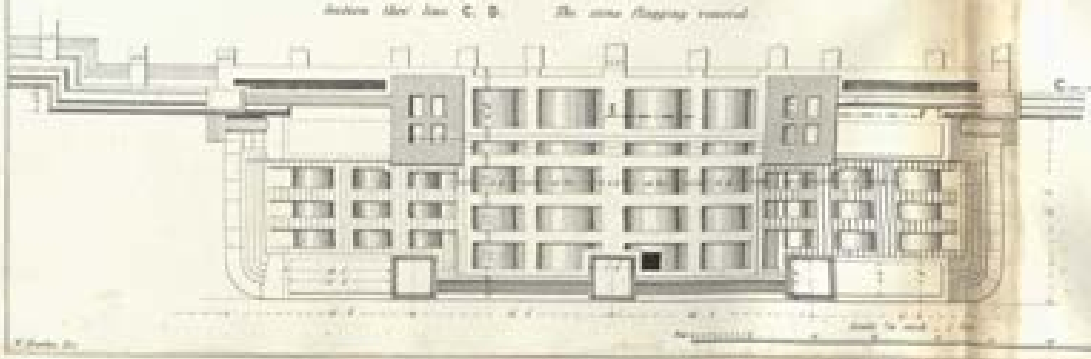
LANDING STAIRS BETWEEN CHARING CROSS & WATERLOO BRIDGES.

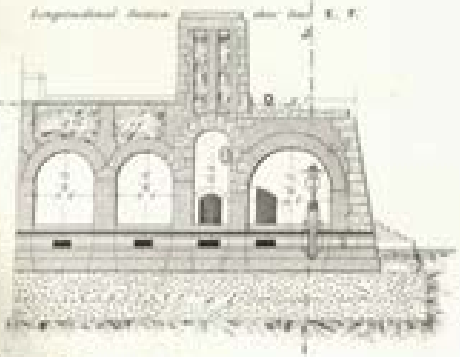


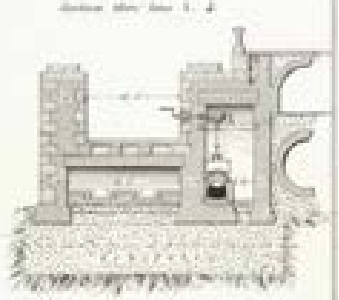












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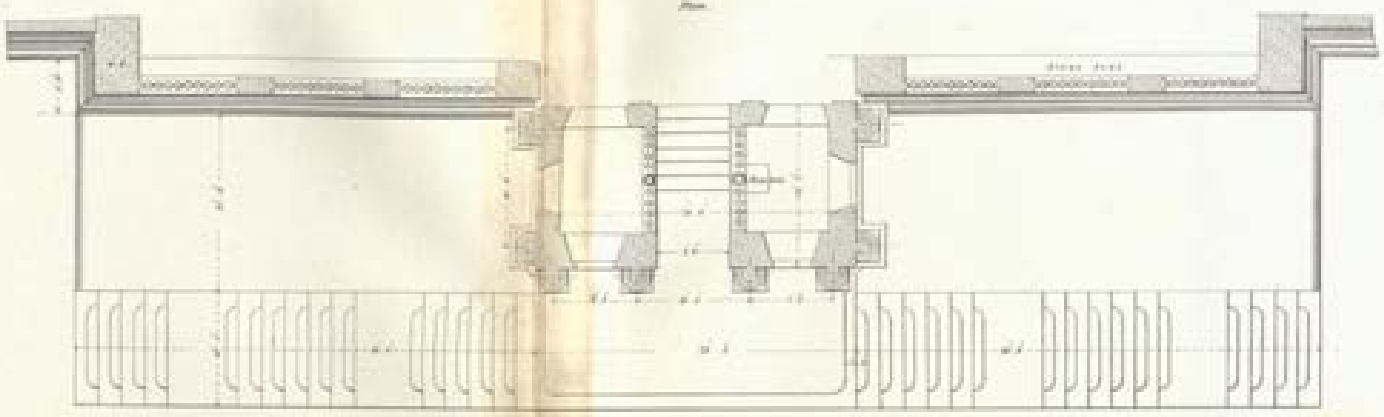
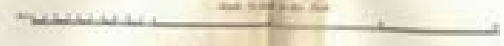
No 1.

YORK GATE.



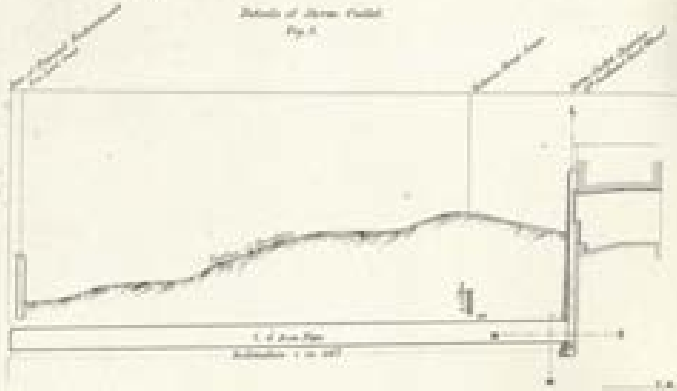


THAMES EMBANKMENT.

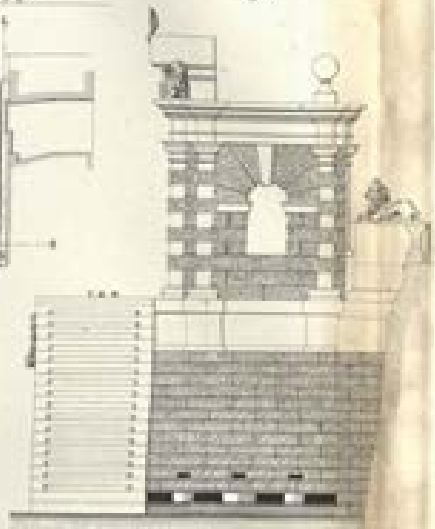
No 6.

YORK GATE

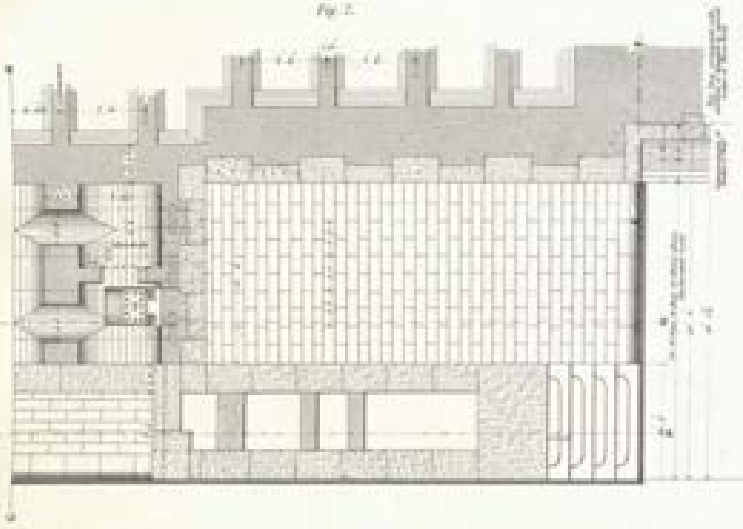
DETAILS OF LANDING STAIRS.



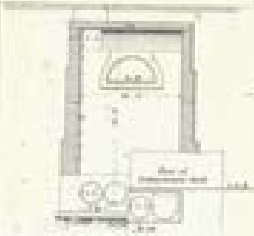
Details of Storm Outlet
Fig 1.



Side Elevation
Fig 2.

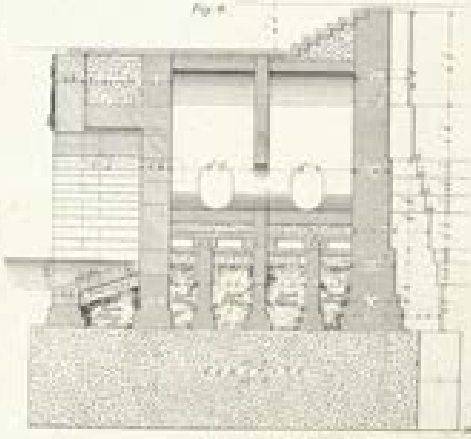


Horizontal Section through Line I. K.
Fig 3.

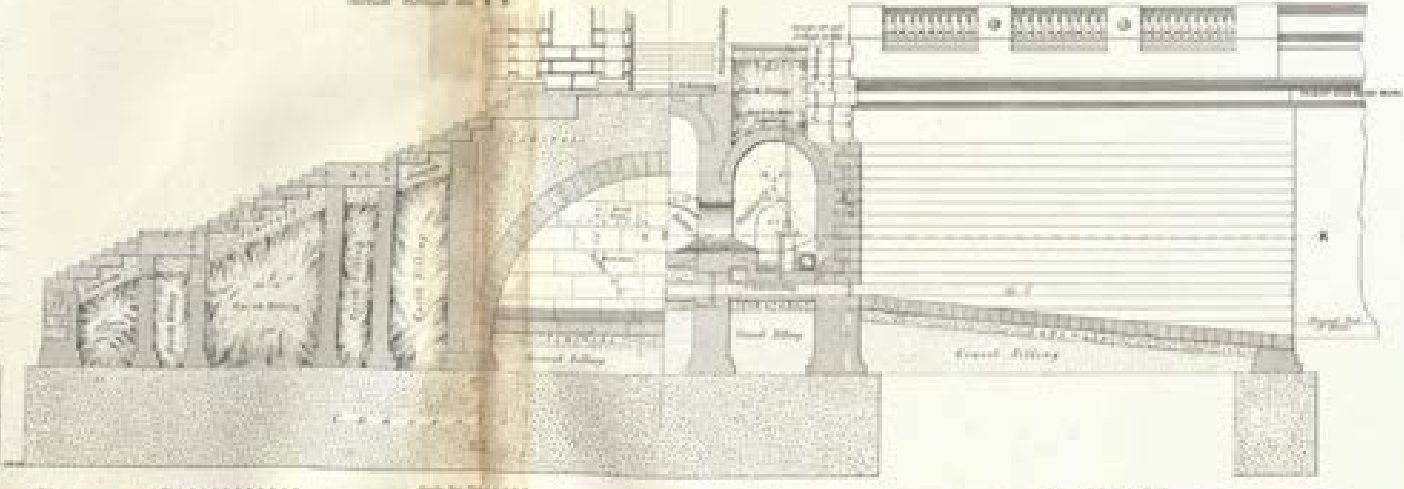


Plan below at L. M.
Fig 4

Plan at N.O.
Fig 5



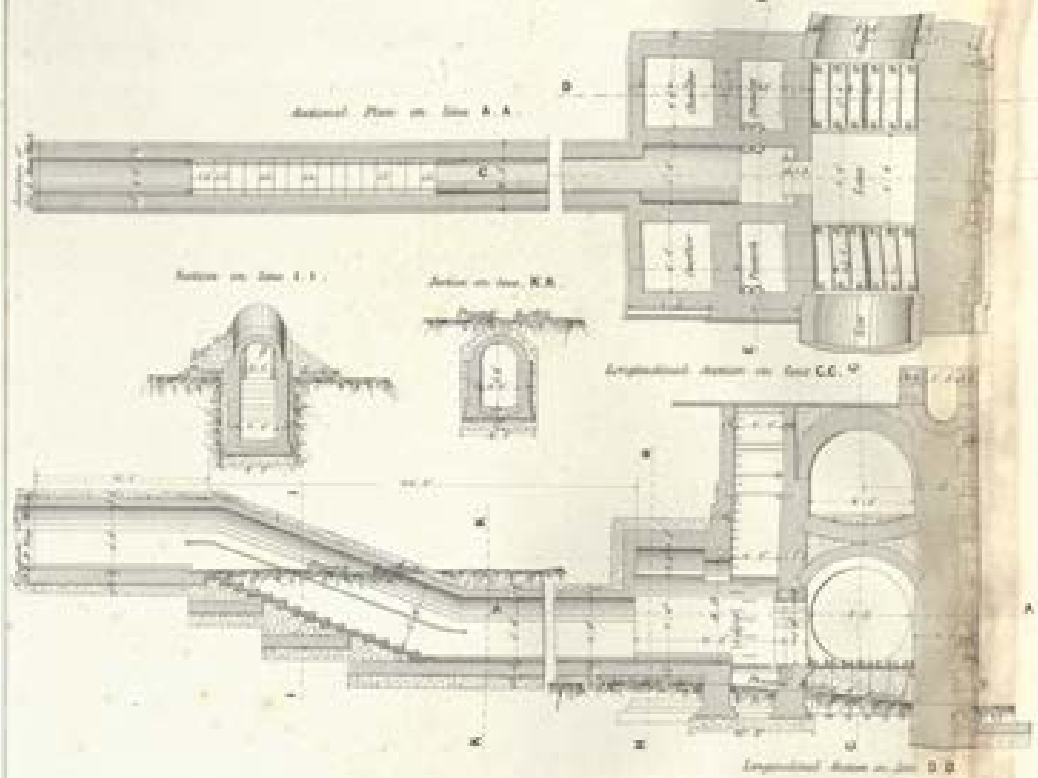
Section through Line G. H.
Fig 6

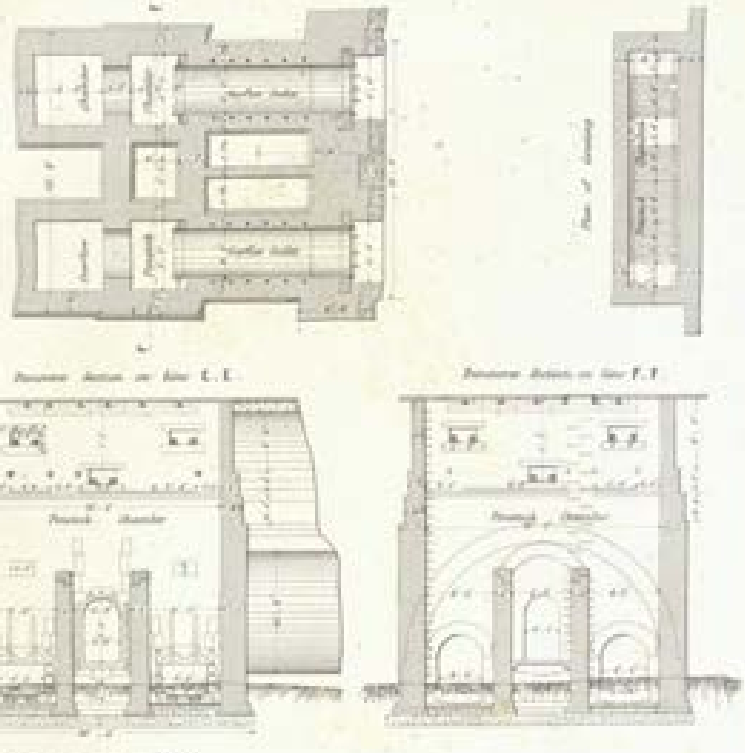


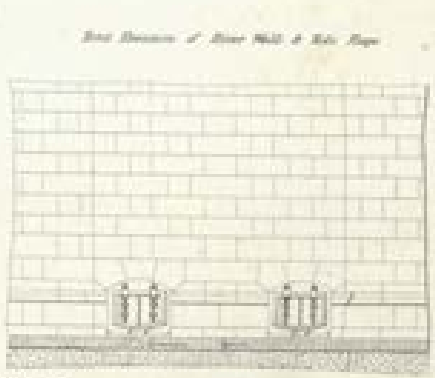
Section through Line A. B.
Fig 7

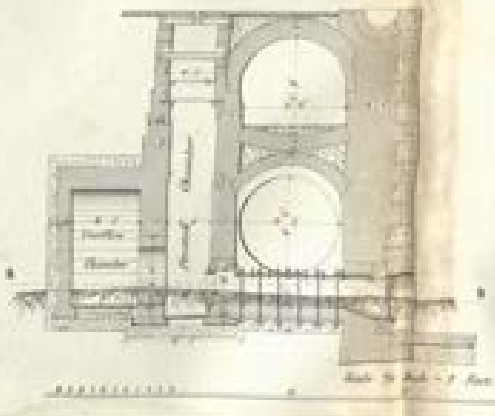
Section through Line C. D.

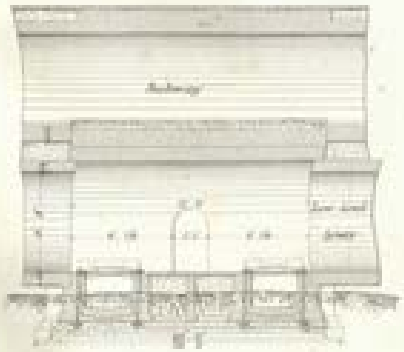
OVERFLOW & OUTLET AT SAVOY ST. SEWER











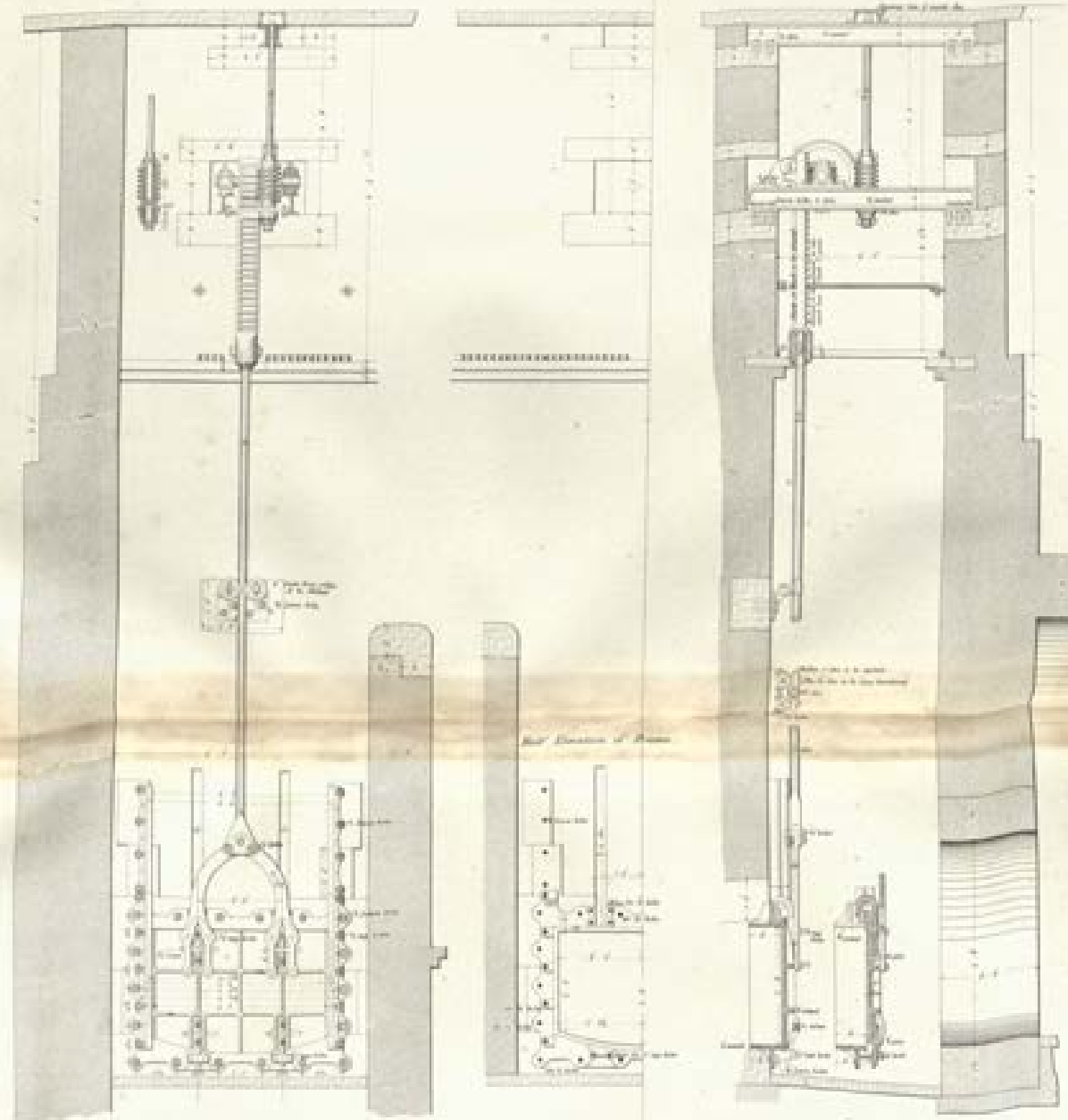
THAMES EMBANKMENT.

No 9

Illustrations of the Principles of Modern Engineering Practice
PLATE XI

SAVOY STREET SEWER.

DETAILS OF PENSTOCK.

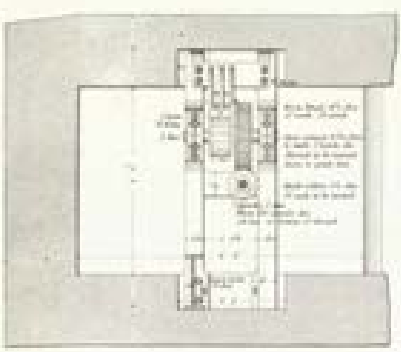


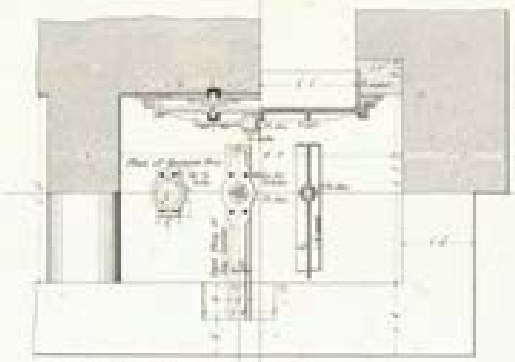
Half Elevation of Penstock

Half Elevation of Penstock

Half Sectional Plan of Penstock

Half General Plan of Penstock





Scale 1 Inch to the Foot

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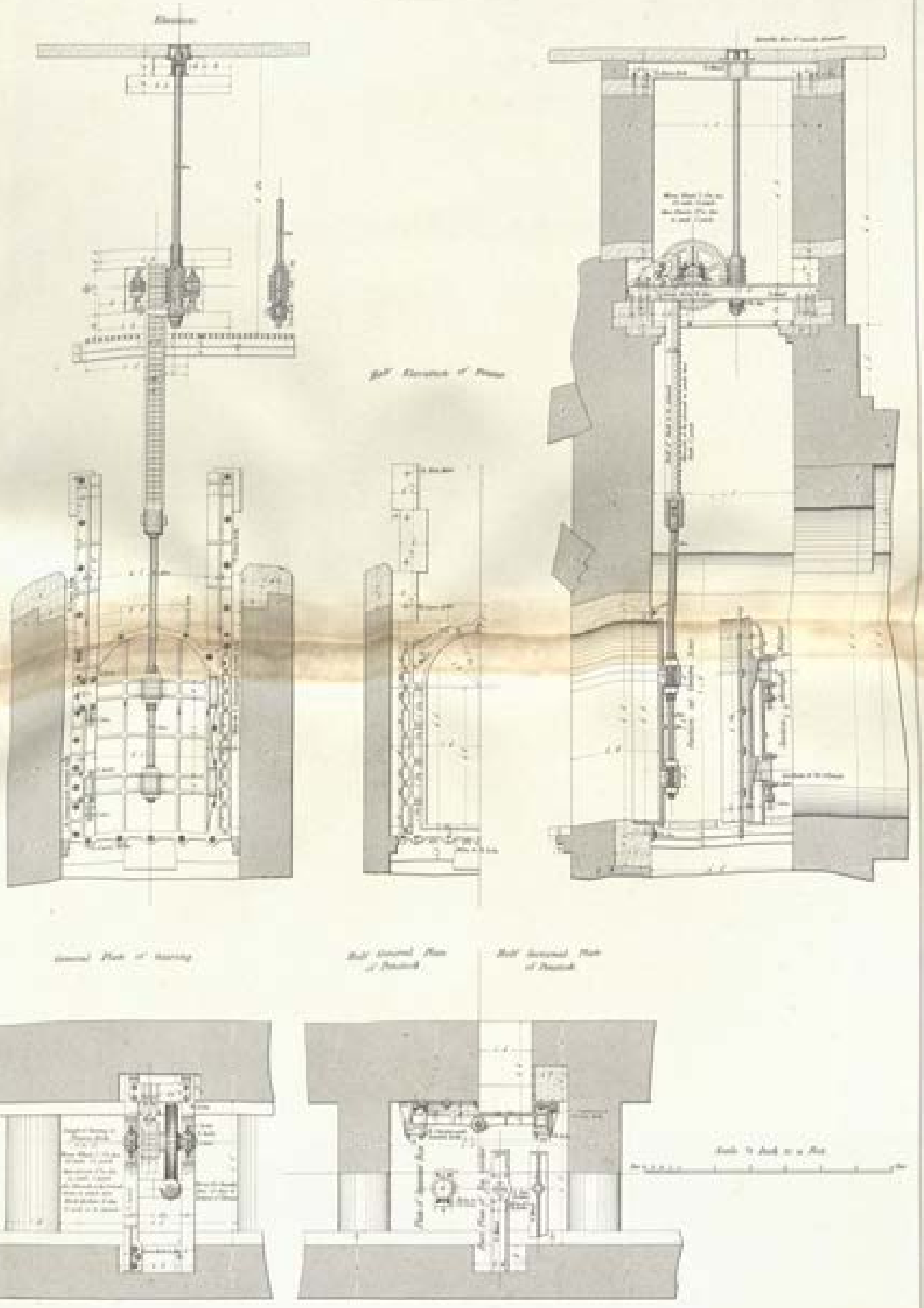
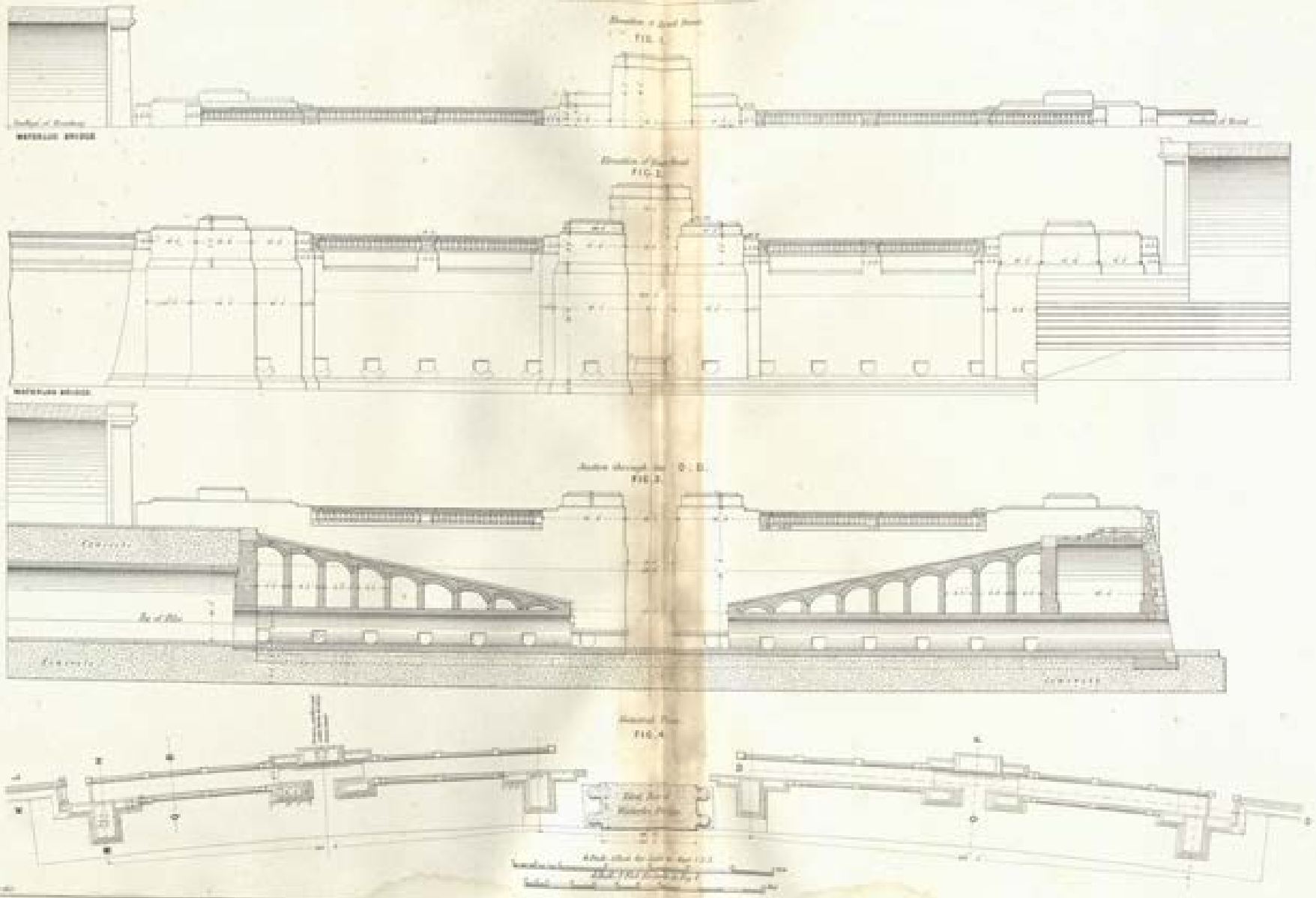
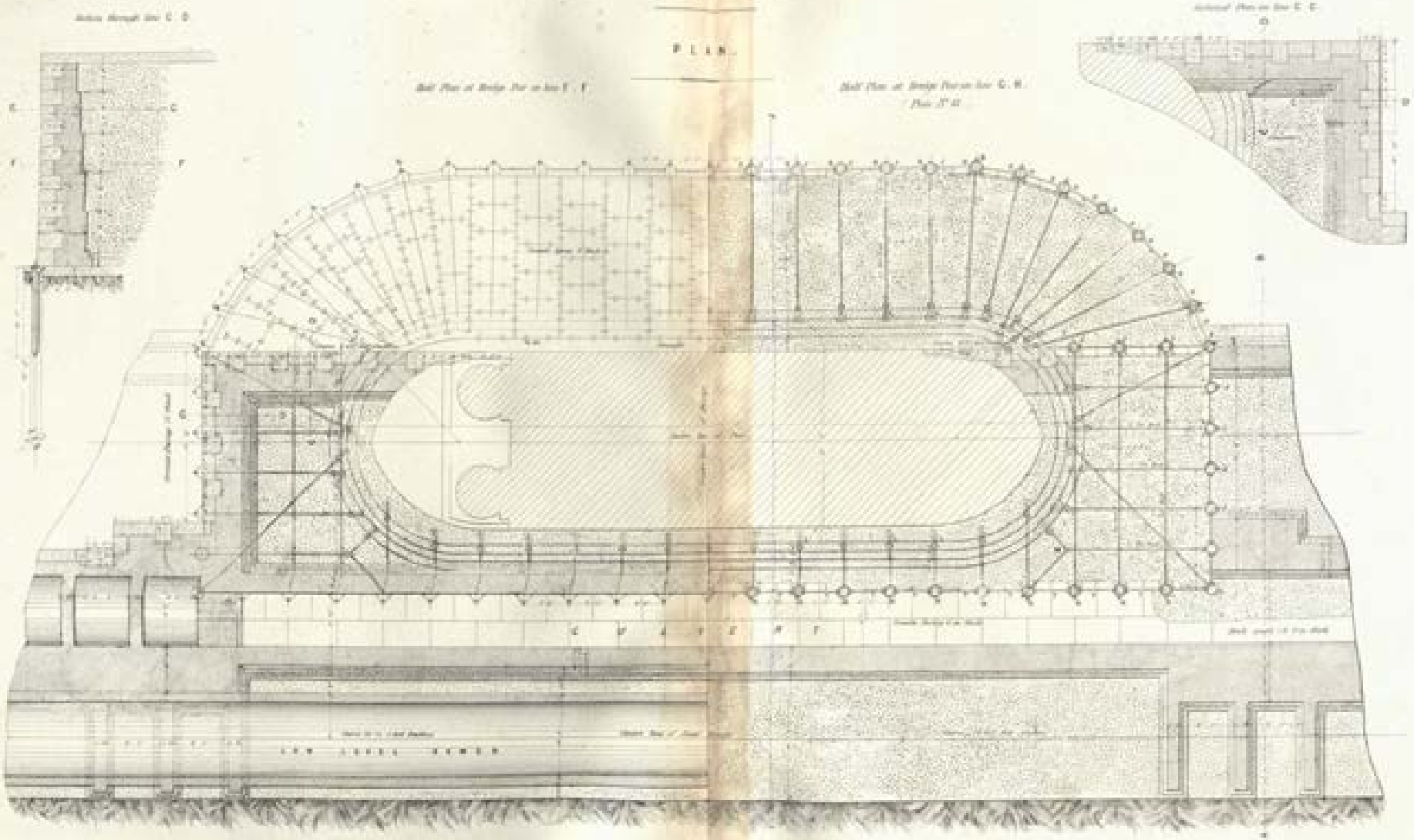
DETAILS OF PENSTOCK FOR SAVOY ST SEWER OUTLET.


Elevation
Half Elevation of Frame
Half Sectional Plan of Penstock
Half Sectional Plan of Penstock
Scale ½ Inch to a Foot

STEAM BOAT PIER AT WATERLOO BRIDGE.



DETAILS OF STEAM BOAT PIER WATERLOO BRIDGE.



THAMES EMBANKMENT.

No 12.

STEAM BOAT PIER AT WATERLOO BRIDGE.

FIG. 1.

Section show Line A. B.

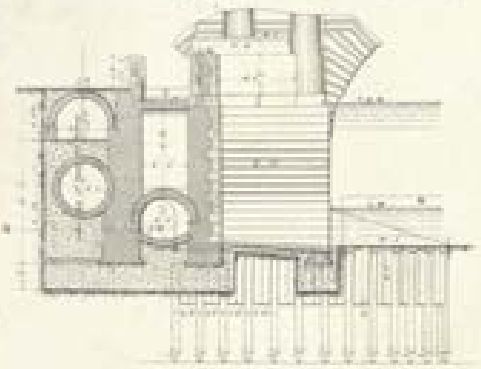
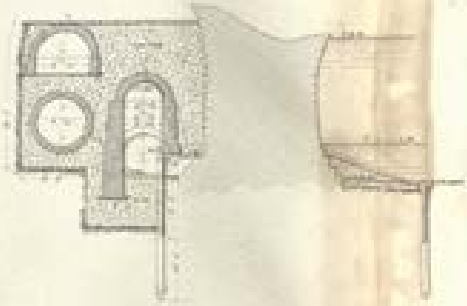


FIG. 2.

Section show Line C. D.



Cast Iron Plate on A.

Section on S.S.

Plan on Top

Front Elevation

Back Elevation

Section on Y.Y.

End Elevation

Cast Iron Plate on T.

Section on R.R.

Plan on Top

Front Elevation

Back Elevation

Section on X.X.

End Elevation

Cast Iron Pillar

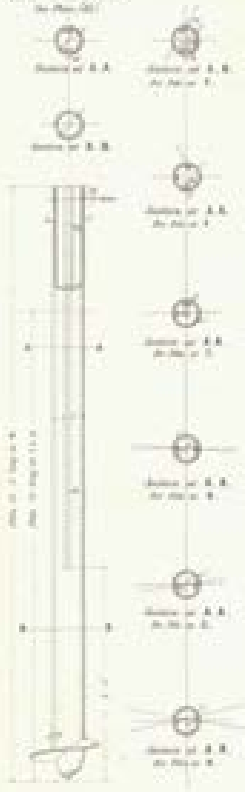


FIG. 3.

Section on Line E. L.

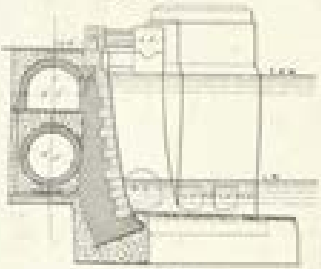
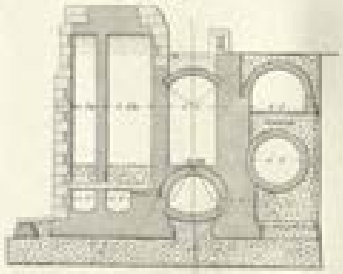


FIG. 4.

Section on Line K. K.



Plan of Section and Elevation of Parapet

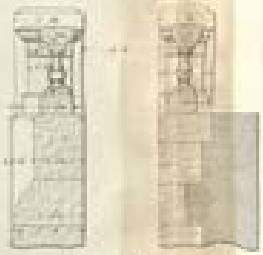


FIG. 5.

Section on Line O. P.

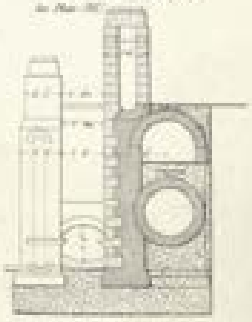
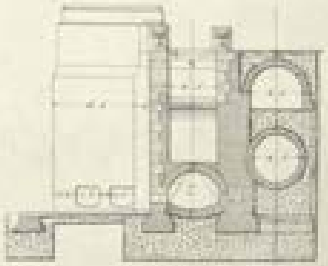
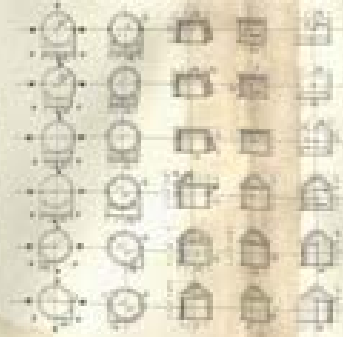


FIG. 6.

Section on Line Q. R.



Cast Iron Pile Caps



Wrought Iron Knee Brace

Plan.

Elevation.

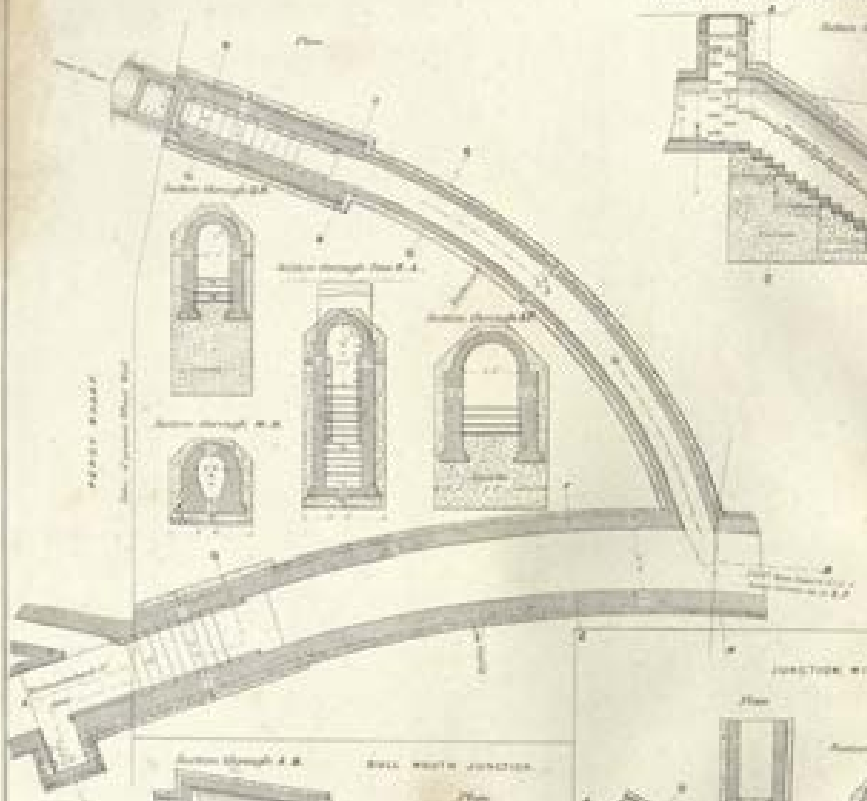
Wrought Iron Diagonal

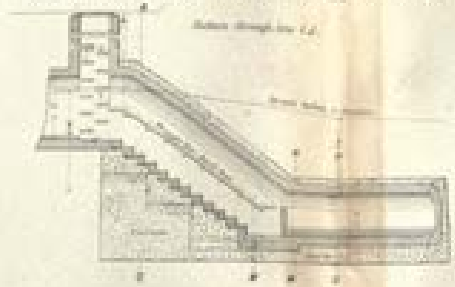
Plan.

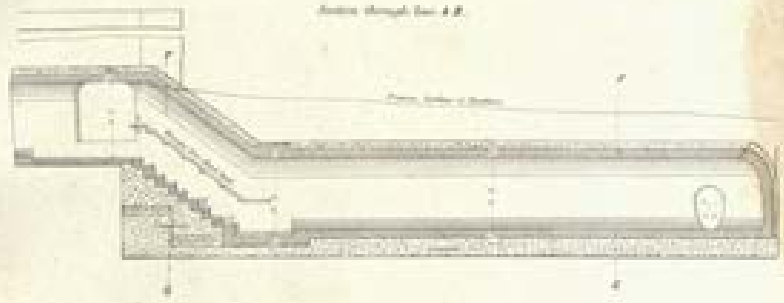
Elevation

SEWERS.

JUNCTION OF NORTHUMBERLAND ST & CRAVEN ST SEWERS

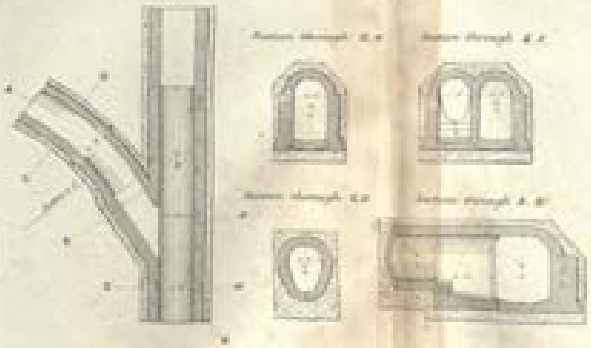






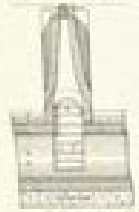
BALL MOUTH JUNCTION.

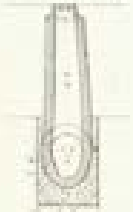
JUNCTION WITH CRAVEN ST SEWER.

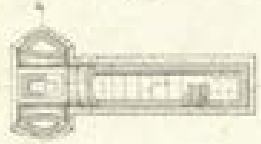


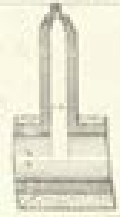
Gale Entrance

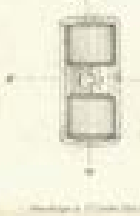
VENTILATING SHAFT







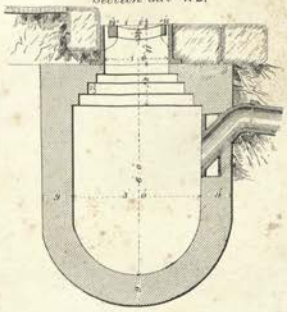




THAMES EMBANKMENT.

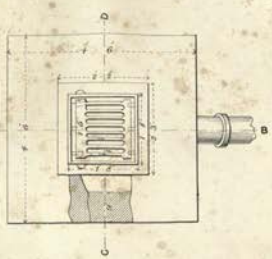
No 14.

Section thro' A B.

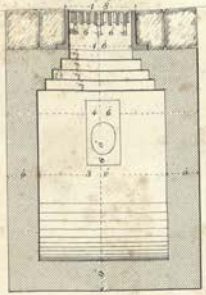


GULLY.

Plan.

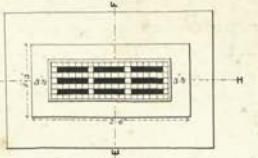


Section thro' C D.



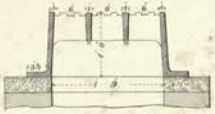
VENTILATING GRATE.

Plan.



Section thro' E F.

Section thro' G H.



SIDE ENTRANCE COVER.

General Plan.

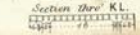
Inverted Plan of Cover.

Plan of Frame.

Inverted Plan of Frame.

Plan of Safety Grate.

Section thro' K L.

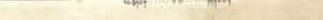


Section thro' Cover and Safety Grate.

Section of Cover thro' I J.

General Scale

Scale for Ventilating Grate.



W Humber. del.

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